Identification	**Subject (code, title, credits)**	ETR 670, Microsystems and nanoelectronics- 8 ECTS
	Department	Physics and Electronics
	Program (undergraduate, graduate)	Graduate
	Term	Fall, 2025
	Instructor	Ph.D. Shirkhan Humbatov
	E-mail:	shirxanhumbatov@gmail.com
	Phone:	
	Classroom/hours	11 Mehseti str. (Neftchilar campus)
	Office hours	Monday: 11:50-15:10/ Thursday: 11:50-15:10
Prerequisites	PHSC 111	
Language	English	
Compulsory/Elective	Compulsory	
Required textbooks andcourse materials	**1.Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al., Springer 2012** **2.Nanoelectronics Fundamentals Materials, Devices and Systems by Hassan Raza, Springer 2019**	
Course outline	This course provides a comprehensive investigation into the physical principles, fabrication techniques, and system-level integration strategies that define the modern field of microsystems and nanoelectronics. Beginning with the fundamentals of semiconductor physics, students will develop a rigorous understanding of carrier transport, band structure, and quantum mechanical effects that emerge as device dimensions approach the nanoscale. The course emphasizes the theoretical framework of nanoelectronics, incorporating quantum confinement, tunneling, and atomistic modeling approaches essential for the design of next-generation devices. Classical transistor scaling will be critically examined, with detailed coverage of MOSFET physics, short-channel effects, and the transition to advanced architectures such as FinFETs, gate-all-around FETs, and nanosheet transistors. Nanofabrication methods—including EUV lithography, electron-beam lithography, and atomic layer deposition—will be presented as both scientific tools and industrial techniques for precise material and device structuring. The module on MEMS and NEMS introduces micro- and nano-electro-mechanical systems as functional platforms for sensing, actuation, and signal processing at the convergence of mechanics and electronics. Students will explore system-level integration approaches, including 3D integration, heterogeneous packaging, and system-on-chip technologies, with attention to reliability, performance, and thermal constraints. Advanced materials for nanoelectronics, such as 2D semiconductors, ferroelectrics, perovskites, and phase-change compounds, will be studied with a focus on their unique electrical, optical, and mechanical properties. The optoelectronics module integrates quantum well, wire, and dot concepts into practical devices such as lasers, LEDs, photodetectors, and nanophotonic components. Reliability and variability at the nanoscale will be addressed through the study of noise mechanisms, degradation pathways, and statistical models of device performance. Computational methods—including TCAD, Monte Carlo simulations, and atomistic transport models—will be utilized to bridge theory with predictive device design. Emerging paradigms such as spintronics, neuromorphic architectures, resistive switching memories, and quantum hardware will be analyzed as potential disruptors of classical scaling trends. The course encourages critical evaluation of the role of microsystems and nanoelectronics in biomedical, environmental, and communication technologies, highlighting both opportunities and limitations. Students will gain practical experience through simulation and design projects, ensuring that theoretical knowledge is directly mapped onto experimental and applied contexts. By the end of the course, graduates will have acquired both a profound conceptual mastery of nanoelectronic device physics and the methodological skills required to innovate in the rapidly evolving landscape of nanoscale systems.	
Course objectives	By the end of this course, students are expected to: **1. Foundational understanding** Attain a rigorous theoretical comprehension of semiconductor physics, quantum mechanics, and nanoscale material science that underpins the operation of micro- and nanoelectronic devices.	

	Demonstrate a critical understanding of scaling laws, quantum confinement, and transport phenomena that govern performance at reduced dimensions. **2. Device-level expertise** Analyze, model, and compare conventional and advanced transistor architectures (MOSFETs, FinFETs, CNT-FETs, Tunnel FETs, etc.) in terms of electrical, thermal, and reliability characteristics. Critically evaluate the limits of CMOS technology and the transition toward emerging nanoelectronic paradigms. **3. Fabrication and integration knowledge** Acquire in-depth expertise in nanofabrication techniques (lithography, epitaxy, atomic layer deposition, etching) with emphasis on precision, reproducibility, and scalability. Understand integration strategies for MEMS/NEMS, heterogeneous systems, and 3D packaging, including reliability and thermal management issues. **4. Advanced materials mastery** Develop the ability to assess the role of novel materials (graphene, 2D semiconductors, ferroelectrics, perovskites) in enabling next-generation nanoelectronic devices. Critically analyze the trade-offs of material choice on device performance, energy efficiency, and integration challenges. **5. Modeling and simulation competence** Apply computational techniques (TCAD, quantum transport simulations, Monte Carlo methods, density functional theory) for device-level and system-level analysis. Employ multiscale modeling to bridge atomistic effects with macroscopic electronic behavior. **6. Reliability and variability analysis** Examine mechanisms of device degradation, noise, and variability at the nanoscale. Formulate reliability prediction frameworks and propose engineering strategies for improving device lifetime. **7. Innovation in emerging technologies** Investigate state-of-the-art nanoelectronic paradigms such as spintronics, memristive systems, neuromorphic circuits, and quantum devices, understanding their operational principles and limitations. Evaluate potential disruptive applications in computing, communication, energy, and biomedicine. **8. Research and professional skills** Design and execute independent research projects in nanoelectronics, integrating both theoretical and experimental methods. Critically engage with contemporary scientific literature, evaluate methodologies, and identify knowledge gaps. Demonstrate effective scientific communication skills through research papers, presentations, and collaborative projects. **9. Ethical and societal context**

	Assess the ethical, societal, and environmental implications of nanoscale technologies. Recognize the role of nanoelectronics in sustainable development, addressing energy efficiency and ecological footprint.
Learning outcomes	**Upon successful completion of this course, the student will be able to:** **1. Theoretical mastery** Critically analyze the quantum mechanical and semiconductor physics foundations that govern the behavior of microscale and nanoscale electronic devices. Formulate and mathematically model the influence of quantum confinement, tunneling, and scaling effects on device characteristics and system performance. Synthesize knowledge from solid-state physics, nanomaterials science, and electronic engineering to explain the principles underlying advanced device architectures (FinFET, GAA, CNT-FET, spin-FET). **2. Technical and methodological competence** Evaluate and apply advanced nanofabrication techniques, including EUV lithography, atomic layer deposition, and nanoimprint lithography, for the design of cutting-edge micro/nanoelectronic structures. Demonstrate proficiency in computational modeling and simulation of nanoscale devices using TCAD, Monte Carlo methods, and atomistic quantum transport simulations. Interpret and assess experimental data from nanoelectronic systems, incorporating error analysis, reliability testing, and process variability considerations. **3. Integration and system-level understanding** Assess and compare different integration paradigms (2D, 2.5D, 3D integration; SoC vs. SiP) for heterogeneous system design. Design conceptual architectures for microsystem integration that combine logic, memory, sensors, and actuators within a unified nanoelectronic framework. Critically evaluate trade-offs between power, performance, area, and reliability in nanoscale device and system design. **4. Research and innovation skills** Formulate research hypotheses in the domain of nanoelectronics and microsystems, grounded in both theoretical frameworks and practical limitations. Design and conduct independent research projects, demonstrating expertise in device modeling, simulation, fabrication, or characterization. Generate novel concepts for emerging device technologies (neuromorphic systems, quantum devices, bio-integrated nanoelectronics), supported by rigorous scientific reasoning. **5. Professional and ethical awareness** Critically reflect on the ethical, environmental, and societal implications of nanotechnology and its deployment in biomedical, communication, and computing industries. Demonstrate awareness of sustainability challenges in semiconductor manufacturing, including energy efficiency, material scarcity, and e-waste management.

<table>
<tr><td></td><td colspan="3">Engage in scholarly communication, presenting advanced technical findings clearly and effectively in oral, written, and visual formats suitable for academic and industry contexts.

6. Lifelong learning and transferable competencies

Integrate interdisciplinary knowledge from physics, chemistry, materials science, and engineering into a coherent understanding of nanoscale systems.

Apply critical thinking and problem-solving skills to new and unforeseen challenges in the rapidly evolving field of nanoelectronics.

Exhibit readiness to pursue doctoral-level research or leadership roles in advanced electronics industries, demonstrating adaptability and innovation capability.</td></tr>
<tr><td rowspan="2">Teaching methods</td><td colspan="2">Lecture</td><td>+</td></tr>
<tr><td colspan="2">Group discussion</td><td>+</td></tr>
<tr><td rowspan="8">Evaluation</td><td>Methods</td><td>Date/deadlines</td><td>Percentage (%)</td></tr>
<tr><td>Midterm Exam</td><td></td><td>30</td></tr>
<tr><td>Atendance</td><td>At each lesson</td><td>5</td></tr>
<tr><td>Quizzes</td><td>During the semester, 4 time</td><td>20</td></tr>
<tr><td>Activity</td><td>During the semester</td><td>10</td></tr>
<tr><td>Final Exam</td><td></td><td>35</td></tr>
<tr><td>Others</td><td></td><td></td></tr>
<tr><td>Total</td><td></td><td>100</td></tr>
<tr><td>Policy</td><td colspan="3">Preparation for class
• The structure of this course makes your individual study and preparation outside the class extremely important. The lecture material will focus on the major points introduced in the text. Reading the assigned chapters and having some familiaritywith them before class will greatly assist your understanding of the lecture. Afterthe lecture, you should study your notes and work relevant problems and cases from the end of the chapter and sample exam questions.

Withdrawal (pass/fail)
• This course strictly follows grading policy of the School of Science and Engineering. Thus, a student is normally expected to achieve a mark of at least60% to pass. In case of failure, he/she will be required to repeat the course thefollowing term or year.

Cheating/plagiarism
• Cheating or other plagiarism during the Quizzes, Mid-term and Final Examinations will lead to paper cancellation. In this case, the student will automatically get zero (0), without any considerations.

Professional behavior guidelines
• The students shall behave in the way to create favorable academic and professional environment during the class hours. Unauthorized discussions and unethical behavior are strictly prohibited.

Attendance
• Students who attend the whole classes will get 5 marks. for three absence student loses 1 mark.

Activity
• Students who will be active during discussion of past lessons and who will be solve homework problems in a seminar will be awarded with one activity mark.

Quizzes
• There will be 2 quizzes examination during the semester. The quizzes will be announced in the classroom two weeks before. Quiz is based on homework problems. The homework problems will be selected from questions and problems in the end of each chapter. The number of homework problems will be announced after finishing each chapter.

The students who able to pass midterm and first quiz with max points automatically get max 10 point for the second quiz.</td></tr>
<tr><td colspan="4" align="center">Tentative</td></tr>
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Schedule			
Week	**Date/Day (tentative)**	**Topics**	**Textbook**
1.	**15.09.25-20.09.25**	**Introduction to Microsystems and Nanoelectronics** Evolution from microelectronics to nanoelectronics Moore's Law and beyond: scaling challenges Applications in computing, sensing, biomedical, and quantum systems Future perspectives in nanoscale integration	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 1. 2. Handnotes given by teacher
2.	**22.09.25-27.09.25**	**Fundamentals of Semiconductor Physics** Energy bands, effective mass, density of states Carrier concentration and statistics (Fermi-Dirac) Carrier transport (drift, diffusion, mobility, scattering) Recombination–generation processes	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 3. 2. Handnotes given by teacher
3.	**29.09.25-04.10.25**	**Quantum Mechanics for Nanoelectronics** Quantum confinement and tunneling phenomena Effective mass approximation in nanostructures Density functional theory (DFT) overview for material modeling Quantum wells, wires, and dots	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 5. 2. Handnotes given by teacher
4.	**06.10.25-11.10.25**	**MOSFET and Advanced Transistor Structures** MOSFET scaling and short-channel effects High-k dielectrics and metal gates FinFETs, Gate-All-Around (GAA), and nanosheet transistors Emerging transistor technologies (tunnel FETs, spin-FETs, CNT-FETs)	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 6. 2. Handnotes given by teacher
5.	**13.10.25-18.10.25**	**Nanofabrication Techniques** Photolithography and extreme ultraviolet (EUV) lithography Electron-beam, nanoimprint, and soft lithography Atomic layer deposition (ALD) and molecular beam epitaxy (MBE) Etching (dry/wet, plasma, RIE) and thin-film processes	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 7. 2. Handnotes given by teacher
6.	**20.10.25-25.10.25**	**MEMS and NEMS Fundamentals** Principles of micro-electro-mechanical systems (MEMS) Scaling laws and surface-to-volume effects Fabrication techniques for MEMS/NEMS Case studies: sensors, actuators, resonators	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 7. 2. Handnotes given by teacher
7.	**27.10.25-01.11.25**	**Integration of Microsystems** System-on-Chip (SoC) vs. System-in-Package (SiP) 2D, 2.5D, and 3D integration Heterogeneous integration of sensors, logic, and memory Packaging and reliability considerations	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 8. 2. Handnotes given by teacher
8.	**03.11.25-08.11.25**	**Midterm Exam** Problem solving	

9.	**10.11.25-15.11.25**	**Nanoelectronic Materials** Low-dimensional materials: graphene, carbon nanotubes, 2D semiconductors (MoS_2, WS_2) Ferroelectrics, multiferroics, and phase-change materials Organic and hybrid perovskite semiconductors Dielectrics and interconnect materials at nanoscale	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 9. 2. Handnotes given by teacher
10.	**17.11.25-22.11.25**	**Nano-Optoelectronics** Quantum well lasers, quantum dot LEDs Photodetectors and photovoltaics at nanoscale Plasmonics and nanophotonics for electronics–photonics integration Applications in communication and imaging	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 15. 2. Handnotes given by teacher
11.	**24.11.25-29.11.25**	**Nanoelectromechanical Systems (NEMS)** Principles of mechanical resonance at nanoscale Coupled electromechanical dynamics Energy harvesting using NEMS devices Applications in RF, sensing, and biological systems	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 16. 2. Handnotes given by teacher
12.	**01.12.25-06.12.25**	**Reliability and Variability in Nanoelectronics** Sources of variability (process, thermal, quantum) Noise in nanoscale devices (1/f noise, random telegraph noise) Device degradation and failure mechanisms Reliability modeling and testing methodologies	1. Fundamentals of Microsystem and Nanotechnology by Zhaoying Zhou et al. Chapter 12. 2. Handnotes given by teacher
13.	**08.12.25-13.12.25**	**Computational Methods in Nanoelectronics** Device simulation (TCAD, Monte Carlo methods) Atomistic modeling and quantum transport simulations Multiscale modeling approaches Machine learning in nanoelectronics design and optimization	1.Nanoelectronics Fundamentals Materials, Devices and Systems by Hassan Raza Chapter 5. 2. Handnotes given by teacher
14.	**15.12.25-20.12.25**	**Emerging Nanoelectronic Paradigms** Spintronics and magnetic tunnel junctions Resistive RAM (RRAM), phase-change memory (PCM), and memristors Neuromorphic computing architectures Quantum computing hardware platforms	1.Nanoelectronics Fundamentals Materials, Devices and Systems by Hassan Raza Chapter 6. 2. Handnotes given by teacher
15.	**22.12.25-27.12.25**	**Applications and Future Directions** Biomedical micro/nano devices (lab-on-chip, biosensors) Internet of Things (IoT) and wearable nanoelectronics Energy-efficient and sustainable nanoelectronics Ethical, societal, and environmental aspects of nanotechnology	1.Nanoelectronics Fundamentals Materials, Devices and Systems by Hassan Raza Chapter 7-8. 2. Handnotes given by teacher
		Final Exam	

This syllabus is a guide for the course and any modifications to it will be announced in advance.