Semiconductors in Neuromorphic Computing

Course description sheet

Basic information

Field of study AGH UST International Courses **Major** All **Organisational unit** AGH University Database of Electives **Study level** University database of electives **Form of study** Full-time studies **Profile** General academic	**Didactic cycle** 2026/2027 **Course code** UBPOJOS.A100000.19081.26 **Lecture languages** English **Mandatoriness** Elective **Block** General Modules **Course related to scientific research** Yes **USOS code** 693-INT-xS-304

Course coordinator	Gisya Abdi
Lecturer	Gisya Abdi

Period Winter semester	**Method of verification of the learning outcomes** Exam **Activities and hours** Lectures: 15 Practical classes: 15	**Number of ECTS credits** 4

Goals

C1	Introduce the fundamentals of semiconductor physics in modern electronic devices.
C2	Explore memristors, resistive switching devices, and next-generation computing architectures
C3	Connect semiconductor principles with practical neuromorphic applications.
C4	To foster critical thinking on the future of semiconductor-based neuromorphic technologies in comparison with conventional computing, emphasizing sustainability, scalability, and interdisciplinary innovation.

Course's learning outcomes

Code	**Outcomes in terms of**	**Learning outcomes prescribed to a field of study**	**Methods of verification**
Knowledge – Student knows and understands:			
W1	Classify semiconductor materials and describe their properties.		Report, Case study, Presentation
W2	Explain principles of resistive switching and memristors.		Report, Case study, Presentation
W3	Evaluate semiconductor roles in neuromorphic computing architectures.		Report, Case study, Presentation
W4	Discuss future challenges and innovations in neuromorphic computing.		Report, Case study, Presentation
Skills – Student can:			
U1	Students will be able to analyze the types of applied semiconductor in the context of electronic devices		Activity during classes, Report, Case study, Involvement in teamwork, Presentation
U2	Students will be able to explain reistive switching materials in neuromorphic circuits for data processing		Activity during classes, Report, Case study, Involvement in teamwork, Presentation
U3	They will develop the knowledge about comparing conventional and unconventional computing methods in real-world applications.		Activity during classes, Report, Case study, Involvement in teamwork, Presentation, Oral answer
Social competences – Student is ready to:			
K1	Students will learn to collaborate in discussions that require interdisciplinary perspectives, integrating materials science, electronics, and computing information.		Activity during classes, Involvement in teamwork, Presentation, Oral answer
K2	Student will learn about the role of neuromorphoic computing in current technology and the challenges facing the development of this field		Activity during classes, Involvement in teamwork, Presentation, Oral answer

Program content ensuring the achievement of the learning outcomes prescribed to the module

The course introduces students to: 1) the fundamentals of semiconductor physics, covering elemental, compound, organic, hybrid, and low-dimensional materials, and their role in modern electronics. It then connects this knowledge to device-level concepts, including transistors, and the limitations of conventional CMOS scaling. 2) Students are introduced to memristors and resistive switching devices and their working principles, material systems, and 3) their role as artificial synapses for neuromorphic architectures. 4) Applications in pattern recognition, speech processing, robotics, and edge AI.

Student workload

Activity form	**Average amount of hours* needed to complete each activity form**
Lectures	15
Practical classes	15
Preparation for classes	30
Contact hours	5
Realization of independently performed tasks	55
Student workload	**Hours** 120
Workload involving teacher	**Hours** 30

* hour means 45 minutes

Program content

No.	**Program content**	**Course's learning outcomes**	**Activities**
1.	The lecture consists of the following modules: 1- Fundamentals of Semiconductor Physics – builds the foundation of electronic properties 2- Types of Semiconductors: introduces conventional and unconventional materials crucial for electronic applications. 3- Introduction to resistive switching devices – covers the core device concept that bridges semiconductors with neuromorphic computing. 4- Memristors in neuromorphic computing, 5- Introduction to neuromorphic computing in data processing	W1, W2, W3, W4	Lectures

No.	Program content	Course's learning outcomes	Activities
2.	Auditorium exercises which help students think more broadly, understand the technologies they use every day, and become familiar with their real-world applications, including: 1- 2D Materials semiconductors 2- Types of neural networks 3- Flexible and wearable neuromorphic devices for brain-inspired sensors and electronics. 4- Comparative study of conventional vs. unconventional semiconductors in neuromorphic systems	U1, U2, U3, K1, K2	Lectures, Practical classes

Extended information/Additional elements

Teaching methods and techniques :

Lectures, Discussion, E-learning, Group work, Socratic questioning, Work with source text

Activities	Methods of verification	Credit conditions
Lectures	Activity during classes, Presentation, Oral answer	With a weight of 50% for the final grade
Pract. classes	Report, Case study, Involvement in teamwork	With a weight of 50% for the final grade

Additional info

The classes will take place in the ACMiN seminar room. Students will first attend lectures and then, as part of the exercises, prepare presentations on assigned topics for in-class discussion. Upon completing the course, students will submit a report addressing the challenges of the discussed topic and its prospects for future technological development.

Conditions and the manner of completing each form of classes, including the rules of making retakes, as well as the conditions for admission to the exam

The condition for passing the lecture is to prepare and deliver a presentation on a given topic covering the issues discussed in the lecture.
To pass the exercises, you must obtain at least 50% of the total points assigned to the individual activities. If you receive an unsatisfactory grade, you will have the opportunity to improve it in the form of a final test on the two subsequent occasions. The maximum grade on the first occasion is 4.0, and on the second occasion - 3.0.

Method of determining the final grade

Final grade for the lecture = grade for a self-prepared and presented presentation on the issues discussed during the lecture
Exercise grade = percentage of the total number of points obtained from individual learning outcomes (exercise completion, activity during classes, preparation of materials and involvement in discussions) scaled according to the following ranges:
91 – 100% very good (5.0),
81 – 90% plus good (4.5),
71 – 80% good (4.0),
61 – 70% plus satisfactory (3.5),
51 – 60% satisfactory (3.0),

Manner and mode of making up for the backlog caused by a student justified absence from classes

The possibility of making up missed work due to a student's absence will be determined individually, depending on the material covered during the class from which the student was absent. Based on this, assignments for independent work will be assigned.

Prerequisites and additional requirements

No prerequisites. This course is intended for students from all AGH faculties who are interested in developing their knowledge about semiconductors and their applications in electronic devices and for neuromorphic computing.

Rules of participation in given classes, indicating whether student presence at the lecture is obligatory

Attendance at classes is mandatory. A maximum of two unexcused absences are permitted.

Literature

Obligatory

1. 1. Wan, Qing, and Yi Shi, eds. Neuromorphic Devices for Brain-inspired Computing: Artificial Intelligence, Perception, and Robotics. John Wiley & Sons, 2022. DOI:10.1002/9783527835317 2. James, Alex, ed. Memristor and memristive neural networks. BoD–Books on Demand, 2018. DOI:10.5772/66539 3. Abderazek Ben Abdallah, Khanh N. Dang, Neuromorphic Computing Principles and Organization, 2025. DOI: 10.1007/978-3-031-83089-1

Optional

1. 1.G. Abdi, et al., Coordination Chemistry Reviews, 2023, 487, 215155. 2. G. Abdi, et al., Advanced Electronic Materials, 2025, n/a, e00049.2025, https://doi.org/10.1002/aelm.202500049 3. V. K. Sangwan and M. C. Hersam, Nature Nanotechnology, 2020, 15, 517-528.DOI:10.1038/s41565-020-0647-z 4. F. Zhang, C. Li, Z. Li, L. Dong and J. Zhao, Microsystems & Nanoengineering, 2023, 9, 16. DOI:10.1038/s41378-023-00487-2

Scientific research and publications

Publications

1. [1] G. Abdi, T. Mazur, E. Kowalewska, A. Sławek, M. Marzec, K. Szaciłowski, “Memristive properties and synaptic plasticity in substituted pyridinium iodobismuthates”, Dalton Transactions, 53, 2024, 14610-14622 [2] G. Abdi, A. Karacali, A. Kamarol Zaman, M. Gryl, A. Sławek, A. Szkudlarek, H. Tanaka, K. Szaciłowski, “7-Methylquinolinium Iodobismuthate Memristor: Exploring Plasticity and Memristive Properties for Digit Classification in Physical Reservoir Computing”, Advanced Electronic Materials, 2025, https://doi.org/10.1002/aelm.202500049 [3] P. Zawal, G. Abdi, M. Gryl, D. Das, A. Sławek, E. Gerouville, M. Marciszko-Wiąckowska, M. Marzec, G. Hess, D. Georgiadou, K. Szaciłowski, “Leaky integrate-and-fire model and short-term synaptic plasticity emulated in a novel bismuth-based diffusive memristor”, Advanced Electronic Materials, 10, 2024, 2300865 [4] E. Cechosz, G. Abdi, A. Sławek, M. Gryl, K. Szaciłowski, “Structure and Spectroscopy of Phenanthroline-Based Iodobismuthate(III) Complexes Utilized for Raw Signal Classification”, Advanced Intelligent Discovery, Under review, 2025 [5] D. Caus, A. Sławek, T. Mazur, P. Zawal, B. Baś, K. Szaciłowski, M. Talanov, G. Abdi, “The memristive implementation of the hippocampus: A hypothesis”, BioNanoScience, under review, 2025, [6] Ch. Mohan , M. Crepaldi, D. Torazza, A. Adamatzky, G.Abdi, A. Szkudlarek and A. Chiolerio, “Liquid ferrofluid synapses for spike-based neuromorphic learning”, Materials Horizons, 12, 2025, 4193-4207 [7] A. Karacali, Y. Nakao, O. Srikimkaew, G. Abdi, K. Szacilowski, Y. Usami, H. Tanaka “Mel-frequency cepstral coefficients feature extracted voice recognition task using atomic switch Ag/Ag2S device-based time-delayed reservoir computing”, Nonlinear Theory and Its Applications, IEICE, 15(4), 2024, 871-882 [8] T. Mazur, G. Abdi, A. Sławek, E. Cechosz, K. Szaciłowski, “Strategies to Finding Optimal Parameters for Plasticity Changes in Memristor-Based Systems for Neuromorphic Data Computing”, BioNanoScience, 15(3), 2025, 409 [9] G. Abdi, L. Alluhaibi, E. Kowalewska, T. Mazur, K. Mech, A. Podborska, A. Sławek, H. Tanaka and K. Szaciłowski, “Reservoir Computing and Photoelectrochemical Sensors: A Marriage of Convenience”, Coordination Chemistry Reviews, 487, 2023, 215155.