COURSE DESCRIPTION CARD - SYLLABUS

Course name

SMART MATERIALS AND METAMATERIALS [S5IMECH>MIM]

Course

Proposed by Discipline
–

Year/Semester
2/3

Level of study
Doctoral School

Course offered in
English

Form of study
full-time

Requirements
elective

Number of hours

Lecture
4

Laboratory classes
0

Other
0

Tutorials
0

Projects/seminars
0

Number of credit points

1,00

Coordinators

dr hab. inż. Hubert Jopek
hubert.jopek@put.poznan.pl

Lecturers

dr hab. inż. Hubert Jopek
hubert.jopek@put.poznan.pl

Prerequisites

Basic knowledge of physics, chemistry, and engineering and technology at the higher education level. A basic understanding of materials science is helpful but not required. Due to the interdisciplinary nature of the course, topics related to material structure, properties, and mechanisms of response to external stimuli will be presented in a manner accessible to doctoral students representing different scientific disciplines and engineering specializations.

Course objective

The aim of the course is to introduce doctoral students to the fundamental concepts of smart materials and metamaterials, with particular emphasis on the relationships between their structure, properties, interactions with the environment, and functional performance. The course will present materials capable of controlled changes in their properties in response to external stimuli, such as temperature, stress, electric and magnetic fields, light, or changes in the chemical environment. The topics discussed will include, among others, shape memory materials, piezoelectric and electroactive materials, magnetorheological and electrorheological materials, and self-healing materials. The second part of the course provides an introduction to metamaterials, whose unusual properties arise primarily from appropriately designed structure, geometry, and architecture rather than solely from the chemical composition of the material. Examples of mechanical, acoustic, and electromagnetic metamaterials will be presented, together with the concept of programming material properties through structural design. An important objective of the course is to demonstrate the interdisciplinary nature of modern materils engineering and its links with mechanics, electronics, automation and control, energy engineering, biomedical engineering, photonics, robotics, manufacturing technologies, and structural design. In addition to gaining knowledge of specific classes of materials, doctoral students should develop the ability to critically evaluate new material concepts and identify potential applications of smart materials and metamaterials within their own research areas.

Course-related learning outcomes

Knowledge
Knows and understands the theoretical foundations and selected recent developments in smart materials and metamaterials, in particular the relationships between material structure, applied stimulus, response mechanism, and resulting function. [SzD_W01]

Knows and understands the main development trends in smart materials and metamaterials, including adaptive and self-healing materials, mechanical, acoustic, and electromagnetic metamaterials, as well as active and reconfigurable structures. [SzD_W02]

Skills
Is able to apply knowledge from different fields of science and engineering to identify and formulate problems in which the use of smart materials or metamaterials may provide new functionalities or innovative engineering solutions. [SzD_U01]

Is able to critically analyze and evaluate solutions based on smart materials and metamaterials, taking into account their operating mechanisms, resulting properties, limitations, and suitability for a specific research or engineering problem. [SzD_U02, SzD_U07]

Social competences
Is ready to critically evaluate scientific and technological achievements related to smart materials and metamaterials, including distinguishing solutions based on well-established scientific principles from concepts with limited technological maturity. [SzD_K01]

Recognizes the importance of knowledge and interdisciplinary approaches in solving cognitive and practical problems related to the design and application of novel functional materials. [SzD_K03]

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

The course is assessed through a problem-based assignment in which the doctoral student selects one smart material or metamaterial and presents its potential application in an area related to their doctoral research.

The analysis should address:
- the problem or engineering need,
- the proposed material or type of metamaterial,
- the input stimulus or operating conditions,
- the material response mechanism,
- the expected function,
- the potential benefits and limitations of the proposed solution.

Assessment criteria:
- scientific and technical correctness,
- understanding of the material's operating mechanism,
- ability to relate material properties to function,
- relevance and justification of the proposed application,
- ability to critically evaluate the benefits and limitations of the proposed solution.

Programme content

1. From conventional materials to smart materials
- the concepts of functional and smart materials,
- the concept: stimulus → response → function,
- interaction of materials with their environment.

2. Materials responsive to external stimuli
- shape memory materials,
- piezoelectric materials,
- electroactive materials,
- magnetostrictive materials,
- magnetorheological and electrorheological fluids,
- materials responsive to changes in temperature, light, and chemical environment.

3. Self-healing and adaptive materials
- the concept of self-healing,
- capabilities and limitations of self-healing materials.

4. Metamaterials – properties through structural design
- the role of unit cells and material architecture,
- effective properties,
- mechanical metamaterials,
- the concept of negative effective parameters,
- structures with programmable properties.

5. Design and manufacturing
- materials design through control of composition and microstructure,
- designing properties through geometry,
- the role of additive manufacturing technologies,
- computational design and optimization,
- prospects for the use of artificial intelligence in materials design.

6. Applications and development trends

Course topics

1. Smart materials
- What does the term "smart material" mean?
- Material stimuli and responses.
- Shape memory effect.
- Piezoelectricity and electroactive materials.
- Materials controlled by magnetic and electric fields.
- Materials with tunable optical properties.
- Examples of applications.

2. Environment-responsive and self-healing materials
- Why do materials become damaged?
- Can a material detect and repair damage by itself?
- Self-healing mechanisms.
- Materials responsive to temperature, pH, humidity, and light.
- Practical limitations.

3. Metamaterials
- From chemical composition to structural design.
- The concept of a unit cell.
- Effective properties of structures.
- Mechanical metamaterials and programmable structures.
- Unusual properties arising from geometry and resonance; “negative” materials.

4. Designing materials of the future
- Combining smart materials with metamaterials.
- Active, adaptive, and reconfigurable metamaterials.
- 3D printing and manufacturing of architected structures.
- Inverse design: “What structure should be designed to achieve a desired property?”
- Computational modelling, optimization, and AI in materials design.
- Analysis of selected examples from current research.
- Discussion: Where can smart materials and metamaterials be applied in the participants’ research?

Teaching methods

- problem-oriented lecture with a multimedia presentation,
- analysis of examples of real materials and engineering solutions,
- discussion,
- relating the technologies discussed to the research areas represented by the doctoral students,
- analysis of selected examples from the scientific literature.

Bibliography

Basic literature

1. D.J. Leo, Engineering Analysis of Smart Material Systems, Wiley, 2007, ISBN 978-0-471-68477-0.
2. E.J. Barbero, Multifunctional Composites, CreateSpace Independent Publishing Platform, 2015, ISBN 978-1-5168-0452-8.
3. K. Bertoldi, V. Vitelli, J. Christensen, M. van Hecke, “Flexible mechanical metamaterials”, Nature Reviews Materials, 2, 17066 (2017), DOI: 10.1038/natrevmats.2017.66.

Additional literature

Current scientific articles on smart materials and metamaterials, in particular mechanical metamaterials, self-healing materials, programmable structures, and stimuli-responsive materials, published in journals such as Advanced Materials, Nature Materials, Materials Today, Smart Materials and Structures, Advanced Functional Materials, Materials & Design, npj Computational Materials, and Computational Materials Science.

Breakdown of average student's workload

	Hours	ECTS
Total workload	25	1,00
Classes requiring direct contact with the teacher	4	0,00
Doctoral student's own work (literature studies, preparation for laboratory classes/tutorials, preparation for tests/exam, project preparation)	21	0,00