ITMO

# ADVANCED FUNCTIONAL MATERIALS

| Course Workload | | Assessment form (examination/ graded test/ ungraded test) |
|---|---|---|
| ECTS | Hours | |
| 6 | 216 | Exam |

By the end of this course, students should be able to define a smart material; identify the different types of smart materials including but not limited to piezoelectric materials, shape memory alloys and shape memory polymers, photovoltaic/optoelectronic materials, electroactive polymers, halochromic materials, chromogenic systems, dielectric elastomers, ferrofluids, thermoelectric materials, chemoresponsive materials, and hybrid materials; identify the stimuli of various types of smart materials (e.g., changes in pH, temperature, humidity; applied magnetic and electric fields; pressure); identify the responses of smart materials to stimuli (e.g., color change, voltage, expansion/contraction); describe smart material syntheses; describe potential smart material applications.

## Course structure:

1. FUNCTIONAL NANO- AND MACROSTRUCTURED MATERIALS, THEIR CLASSIFICATION, STRUCTURE AND PHYSICAL PROPERTIES
   - 1.1. Introduction. Overview of current trends in functional materials science.
   - 1.2. Priority directions of modern research.
   - 1.3. Main information resources.
   - 1.4. Classification and design of functional materials (dimensional, structurally sensitive, "property-sensitive" criteria), nanotechnology of ultrafine materials, molecules, clusters, etc.
   - 1.5. Classification of crystal properties. Polycrystalline functional materials.

2. PHYSICAL AND CHEMICAL BASES OF FUNCTIONAL RESPONSE OF MATERIALS
   - 2.1. Fundamental relationship: chemical composition — atomic structure — microstructure — macro properties of functional nano-, micro- and macrostructured materials.
   - 2.2. The role of dimensional effects in the formation of macroscopic properties.
   - 2.3. Metamaterials.
   - 2.4. Mechanical, electrical, thermal and optical properties of nanomaterials.
   - 2.5. Magnetic properties and their nature. Magnetic ordering. Ferro-, antiferro-, ferry-, para-, diamagnetism. Superparamagnetism of metal nanoparticles or complex oxides.
   - 2.6. Chemical properties of nanomaterials.

3. FUNDAMENTALS OF THE ELECTRONIC STRUCTURE OF CONDENSED MEDIA. CONDUCTORS, SEMICONDUCTORS, DIELECTRICS
   - 3.1. Quantum-mechanical approach to the description of the wave properties of an electron. Schrodinger equation.
   - 3.2. Electron in free and confined space, boundary conditions for simple and symmetric systems. Brillouin zone.
   - 3.3. Electronic properties of crystals. Fundamentals of zone theory. Conductors and semiconductors.

3.4. The concept of dielectrics. Methods for controlling the electrical properties of conductors, semiconductors, dielectrics.

4. CRYSTALS. STRUCTURE, SYMMETRY, DEFECTS AND RELATED PROPERTIES

4.1. Basic principles of crystal lattice formation. Dense packing of atoms in space.
4.2. Features of the formation of cationic-anionic crystal lattices.
4.3. Structure of crystals with covalent nonpolar interatomic bond.
4.4. Symmetry of crystalline substances and their physical properties. The Neumann principle
4.5. Fundamentals of physical chemistry of defects in crystals.
4.6. Methods of controlling the concentration of defects and their effect on the properties of crystals.

5. PROMISING MATERIALS FOR NEUROMORPHIC ELECTRONICS

5.1. Neuromorphic systems and artificial intelligence. Key stages of creating artificial neural networks. Modern trends and challenges.
5.2. Mathematical and physical models of a neuron. Promising directions of modern neuromorphic electronics.
5.3. Memristive systems. Memristor: device, functional properties and manufacturing methods.
5.4. Possibilities of applying the properties of synaptic plasticity of memristors in physical models of artificial neural networks.

6. SMART MATERIALS: DEFINITION, CONCEPTS, AND CLASSIFICATION

6.1. Smart materials definition. Basic concept of smart materials.
6.2. Types of stimuli and responses.
6.3. Smart materials classification. Smart materials that have been inspired by nature.
6.4. Stimuli-responsive materials.
6.5. Methods used in smart material fabrication; research methods.

7. PIEZOELECTRIC MATERIALS. SHAPE MEMORY MATERIALS. MAGNETIC FIELD-RESPONSIVE SMART MATERIALS

7.1. Piezoelectric effect. How piezoelectric materials work. Properties of piezoelectric materials. Advantages and disadvantages of piezoelectric materials. Applications of piezoelectric materials.
7.2. Basic concept of shape memory materials. How shape memory materials work. The effect of temperature on shape memory materials. Shape memory effect. One-way shape memory. Two-way shape memory. The effect of stress/strain on shape memory materials. Advantages and disadvantages of shape memory materials. Applications of shape memory materials.
7.3. Classes of magnetic materials. Magnetic assembly of responsive optical nanomaterials. Magnetic assembly for soft robotics and actuators. Advanced manufacturing of micro- and nanosized actuators for diverse applications.

8. HYBRID MATERIALS

8.1. Basic concept of hybrid materials.
8.2. Hybrid material synthetic methods: building block approach, sol-gel method, blending method, and emulsion polyumerisation.
8.3. Different approaches to hybrid material classification: type of modification vs type of interactions.
8.4. Class I and Class II hybrids.
8.5. Weak physical interactions including van der Waals forces, hydrogen bonding, and electrostatic interactions; strong chemical bonding including ionic, covalent, and coordinate bonding.
8.6. Self-assembly: the weak physical interactions between the organic and inorganic components of hybrid materials.
8.7. Synergism.