Interaction of light with matter is a continuous subject of basic research. This is confirmed by e.g. current research on the properties of electromagnetic metamaterials, liquid crystals and plasmonics - a new interdisciplinary field of research of meso- and nanoscopic systems.

An extremely important from a cognitive point of view is research of microscope, multi-component structures in which a synergistic effect (i.e. interaction of phenomena and physical properties of elements which are components of the structure) is used. Development, manufacture and studies of liquid crystal transducers with metamaterial nanostructures - with tunable refraction properties - to detect their new functionalities are an important, current and prospective field of scientific and research activities, to which this project should be included.

Employing results of previous studies, our experience and current knowledge of the construction of metamaterial transducers our goal is to design, create and test of liquid crystal transducers with metamaterial nanostructures with tunable refraction properties as well as the synthesis of liquid crystals doped with ferroelectric nanoparticles through which it is possible to tune them in a wide spectral range.

Electromagnetic metamaterials produced by means of advanced technologies are artificial structures with properties which generally do not exist in nature. They are composite materials exhibiting negative refraction, due to the fact that their interaction with the electric and magnetic field of electromagnetic wave is resonant. This creates a new, spectacular opportunities to increase the resolving power of optical devices, and overcome the diffraction limit. Metamaterials were theoretically predicted by V. Veselago in 1968. Practically, up to the 1996 researchers did not deal with this topic, but over the past few years we can notice a significant increase of interest in structures exhibiting negative refractive index. The electromagnetic wave falling on the artificial metamaterial interacts with it in such way that below the plasma frequency permeability and permittivity takes negative values and thus an effective refractive index is negative. The periodicity of metamaterials must be much smaller than the wavelength of the impinging electromagnetic wave. The consequence of negative values of permeability and permittivity is diversity the phase and group velocity of the electromagnetic wave.

Metamaterial nanostructures are plasmonic materials of metal-dielectric type with resonant frequencies in the range of 700-1000 nm. They will be made of noble metals (mainly gold and silver) on quartz and polypropylene substrates. Metamaterials with negative index of refraction will be obtained by the juxtaposition of the structures which are the source of negative permittivity ε (e.g. nanowires), with the structures which are the source of negative permeability μ (e.g. split square resonators), contained in one unit cell. Their parameters will be determined in numerical simulation in Quick Wave 3D. Development of metamaterial transducers gives us opportunity to tune their parameters: electrically (by switching the liquid crystal alignment, induced by applying an external voltages), thermally (transition from liquid crystal to isotropic state), and mechanically (tunability is a function of the angle of deflection of metamaterial structure). With an external electric field, the effective refractive index can be reversibly shifted from negative, trough zero, to positive values. Thermally tunable metamaterial transducers may be realized by employing thermotropic liquid crystals. Additionally, the use of polypropylene for the construction makes them flexible and we can tune their parameters mechanically. So far, nobody in the world has not examined the properties of liquid crystal transducers with metamaterial nanostructures which can be electrically, thermally and mechanically tunable. In order to optimize tunability parameters of metamaterials, high birefringence NLCs with optimized dielectric constants, and low losses in wide frequency range are needed. Liquid crystal materials should posses a wide temperature range of the nematic phase and a low viscosity. The order parameter and birefringence of liquid crystals may be increased by doping them with ferroelectric nanoparticles. Results connected with the implementation of the project will be unique in the world.

Currently, production of metamaterial structures for near-infrared range may causes many technological problems. Metamaterial nanostructures with high repeatability may be realized by methods with a resolution less than 50 nm. Such resolution may be obtained by e.g. e-beam lithography. Transverse dimensions of metamaterial nanostructures for near-infrared range are in the range of tens of nanometers. The metallic layers with a thickness of 100-200 nm will be produced employing electron beam physical vapor deposition. This system is equipped with ion sources. These ion sources are used for substrate etching and cleaning, sputtering the target and controlling the nanostructure of the substrate. A critical parameter is the surface roughness of the metallic layers, with which properties of metamaterial structures are getting worse.

Project is extremely innovative and include studies of a new class of materials that can revolutionize many sectors of our life in the near future. Nowadays most of metamaterials are static and passive, restricting their applications. Making metamaterials tunable is desirable because it would enable on-demand switching of their properties. Since the discovery of strong local field enhancement within metamaterials, there are new opportunities to control their properties and operating bandwidth. According to our knowledge no one in the world has made a comprehensive analysis of metamaterial nanostructures in near-infrared range, which can be mechanically, electrically and thermally tunable.

New functional materials with tunable properties will be realized in this project. They can provide a basis for the preparation of novel photonic and optoelectronic devices e.g. optical modulators, filters, absorbers or tunable phase shifters, with parameters impossible to obtain employing currently used materials.