Electrically tuned optical phenomena in metal-oxide-semiconductor multilayer metamaterial

In the past few years we are witnessing an incredible development of the field of photonics. This is a result of the large array of tools that have become available for precise fabrication and characterization, and also because of the availability of powerful electromagnetic simulation methods that are critical for understanding physical phenomena in the micro and nanoscales. On these foundations the concept of metamaterials was born – structures which unique effective optical properties derived from geometrical arrangement of subwavelength elements rather than the constitutive materials properties. The field of optical metamaterials has emerged as one of the most exciting topics in the science of light, and opened a whole new world of fundamental studies and practical applications that were quite undreamt of in the realm of conventional optics. Among many unexpected outcomes we can mention the discovery of negative refraction, optical magnetism, giant chirality, invisible cloaking, novel light sources, hydrogen generation, artificial nonlinearities and very recent passive cooling below the ambient temperature.

We intend to move towards the next step in this revolution, which is the development of active and controllable metamaterials. In order to achieve this goal we want to exploit the fact that under applied electrical field there is a formation of carrier accumulation layer on the interface between oxide-semiconductor. It was recently reported that, the local change of refractive index in this layer can be on the order of unity! Unfortunately, since the thickness of this carrier accumulation layer is only a few nanometres, its presence hardly influences free propagating light beams. We believe that only by combining this phenomena with the concept of the metamaterials we can fully exploit its potential.

The main goal of the project is to elucidate how the process of electrically controlled formation of carrier accumulation layers on ITO-oxide interfaces affects the linear and nonlinear optical properties of the metal-oxide-semiconductor multilayer metamaterial. The expected results that move beyond the current state of the art aim at the first theoretical and experimental demonstration of electrically tuneable multilayer metamaterial, which unique optical properties like e.g.: spatial and temporal frequency filtration, hyperbolic dispersion, superresolving imaging, perfect absorption or enhanced nonlinear response can be modified across the VIS and NIR spectrum ranges simply by the applied voltage.

The project covers thematically various scientific areas starting from linear and nonlinear optics through the concept of metamaterials and ending on semiconductor physics. The problem of electrically tuned metamaterials will be investigated theoretically, numerically and experimentally. The planned research will give us insight into light interactions in the presence of accumulation layers in multilayer geometry, deepened understanding of the carrier accumulation layers formation process, improved knowledge about interfacial processes and also will contribute to development of material science and fabrication techniques. Since the ability to receive, tune or emit electromagnetic waves is the basis for a myriad of highly relevant technological devices which are foundations of the modern world, we believe that the basic research envision in this project will contribute to the development of technologies of the future. In particular we aim at ultrafast electrical and optical modulators, tuneable temporal and spatial frequency filters and electrically controlled optical nonlinearities.