Ultra-compact plasmonic waveguide modulators

Metal-dielectric interfaces can support the waves known as surface plasmon polaritons, which are tightly coupled to the interface and allow manipulation of light at the nanoscale. Plasmonics as a subject which studies such waves enables the merge between two major technologies: nanometer-scale electronics and ultra-fast photonics. Plasmonic technologies can lead to a new generation of fast, on-chip, nanoscale devices with unique capabilities. In particular, it could offer a higher bandwidth and reduced power consumption. Recently, there have been efforts towards addressing the challenge of developing new material platforms for integrated plasmonic devices. Furthermore, novel plasmonic materials such as transparent conductive oxides and transition metal nitrides can offer a variety of new opportunities. In particular, they offer adjustable/tailorable and nonlinear optical properties, dynamic switching and modulation capabilities, low cost, and stability being mean time fully CMOS compatible. The plasmonic devices utilizing new materials could easily be integrated with existing nanophotonic and nanoelectronic devices into complex device geometries, bringing new levels of integration and functionalities. Similar to the advances in silicon technologies that led to the information revolution worldwide, the development of new plasmonic devices could revolutionize the field of hybrid photonic/electronic devices.

To manipulate light in hybrid photonic/electronic circuits based on CMOS-compatible materials, both passive and active plasmonic waveguide components are important. Among other proposed plasmonic waveguides and modulators, the structures where the dielectric core is sandwiched between metal plates have been shown as one of the most compact and efficient layout. Because of the tight mode confinement that can be achieved in metal-insulator-metal structures, they provide a base for extremely fast and efficient ultracompact plasmonic devices, including modulators, photodetectors, lasers and amplifiers.

The main result of this thesis is a systematic study of various designs of plasmonic modulators based on ultra-compact waveguides with different active cores. Plasmonic modulators with the active core such as indium phosphides or ferroelectrics sandwiched between metal plates have promising characteristics. Apart from the speed and dimensions advantages, the metal plates can serve as electrodes for electrical pumping of the active material making it easier to integrate. Including an additional layer in the plasmonic waveguide, in particular an ultrathin transparent conductive oxide film, allows the control of the dispersive properties of the waveguide and thus the higher efficiency of the plasmonic modulator. The main focus of the thesis is how to increase the extinction ratio of plasmonic devices decreasing mean time their propagation losses. Detailed simulations of different configurations are performed and working characteristics are compared to identify the most effective regimes and layouts of the ultra-compact plasmonic modulators.