Sub-wavelength resonant structure opens the path for fine controlling the near-field at the nanoscale dimension. It constitutes into macroscopic “metamaterial” with macroscale properties such as transmission, reflection, and absorption being tailored to exhibit a particular electromagnetic response. The properties of the resonators are often fixed at the time of fabrication wherein the tunability is demanding to overcome fabrication tolerances and afford fast signal processing. Hybridizing dynamic components such as optically active medium into the device makes tunable devices. Alternatively, microelectromechanical systems (MEMS) are a promising platform that can be merged with nanophotonics because they share a modified integrated circuit fabrication process. The prospect of enormous freedom in integrating nanophotonics, microelectromechanical systems actuators and sensors, and microelectronics into a single platform has driven the rapid development of MEMS-based reconfigurable optical devices. This thesis describes the design and development of four tunable plasmonic structures using active media or MEMS, two graphene-based MEMS sensors and a novel tape-based nanotransfer printing techniques.

First of all, we present two tunable plasmonic devices with the use of two active medium, which are electrically controlled liquid crystals and temperature-responsive hydrogels, respectively. By incorporating a nematic liquid crystal layer into quasi-3D mushroom plasmonic nanostructures and thanks to the unique coupling between surface plasmon polariton and Rayleigh anomaly, we have achieved the electrical tuning of the properties of plasmonic crystal at a low operating electric field. We also present another tunable plasmonic device with the capability to sense environmental temperature variations. The device is bowtie nanoantenna arrays coated with a submicron-thick, thermo-responsive hydrogel. The favorable scaling of plasmonic dimers at the nanometer scale and ionic diffusion at the submicron scale is leveraged to achieve strong optical resonance and rapid hydrogel response, respectively.

Secondly, we present two MEMS/NEMS-based tunable near-to-mid infrared metamaterials on a silicon-on-insulator wafer via electrically and thermally actuating the freestanding nanocantilevers. The two devices are developed on the basis of the same fabrication process and are easy-to-implement. The electrostatically driven metamaterial affords ultrahigh mechanical modulation (several tens of MHz) of an optical signal while the thermo-mechanically tunable metamaterial provides up to 90% optical signal modulation at a wavelength of 3.6 µm.

Next, we present MEMS graphene-based pressure and flow sensors realized by transferring a large area and few-layered graphene onto a suspended silicon nitride thin membrane perforated with micro-through-holes. Due to the increased strain in the through-holes, the pressure sensor exhibits a very high sensitivty outperformed than most existing MEMS-based pressure sensors using graphene, silicon, and carbon nanotubes. An air flow sensor is also demonstrated via patterning graphene sheets with flow-through microholes. The flow rate of the air is measured by converting the mechanically deflection of the membrane into the electrical readout due to the graphene piezeroresistors.

Finally, we present a tape-based multifunctional nanotransfer printing process based on a simple stick-and-peel procedure. It affords fast production of metallic and dielectric nanophotonic devices and metamaterials using Scotch tape.