Active Conducting Oxide Plasmonics and Metasurfaces

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Controlling the flow of light is fundamental to optical applications. With the recent advances in experimental and nanofabrication capabilities and new theoretical concepts, ground breaking platforms for the nanoscale manipulation of light and enhancement of light-matter interaction have been demonstrated in recent years. These include plasmonic and metasurface structures,[1] which offer unique optical features such as sub-wavelength field confinement, unusual optical constants and advanced wavefront shaping.

While plasmonic and metasurface structures have been extensively investigated in the last decade, the electromagnetic responses of those structures are usually fixed at the time of fabrication. In addition, current plasmonic and metasurface systems encounter high optical loss due to the electronic transition absorption of metal, therefore, the investigation of efficient active control of light at the nanoscale dimension with external electric or optical fields using alternative low loss materials is important for broadening their possible field of application.

In this talk, I will discuss the use of alternative plasmonic materials, i.e., transparent conducting oxides (TCOs),[2] to actively electrical control the optical properties of plasmonic and metasurface structures for studying new optical physics and advanced applications. This approach combines the advantages of i) the large optical tunability of conducting oxide materials, ii) the field-effect dynamics of metal-oxide-semiconductor (MOS) transistor, and iii) the high field confinement of the plasmonic/metasurface structures to achieve strong control on the electron carrier density of the active conducting oxide layers for the realization of tunable plasmonics and metasurfaces (see Figure).

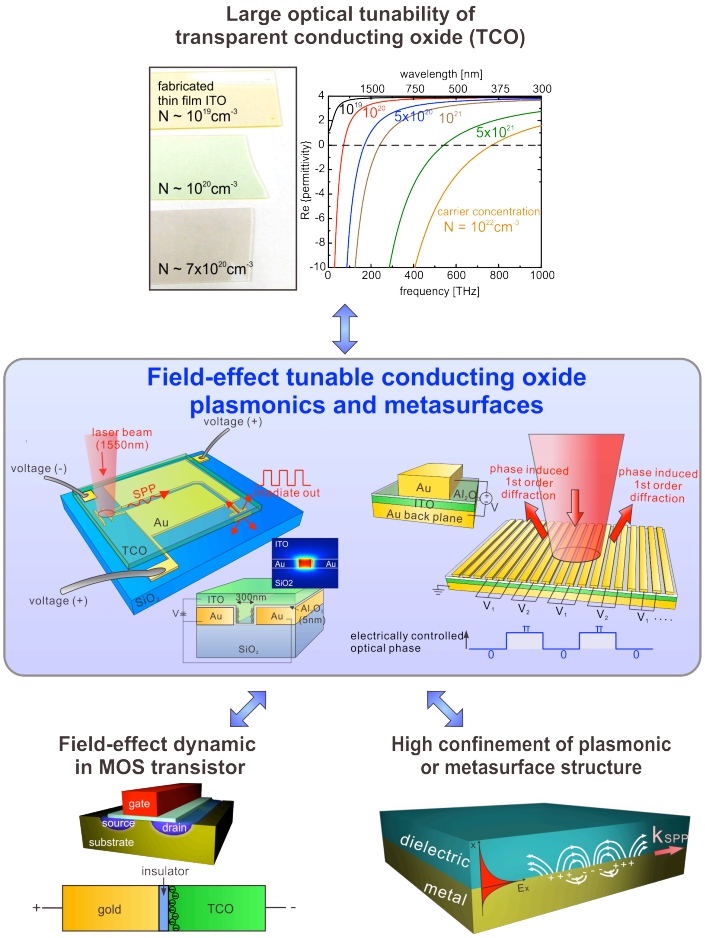

Figure: Conceptual schematic of conducting oxide field-effect tunable plasmonics and metasurfaces. The concept merges the utility of the tunability of conducting oxide materials, the field-effect dynamic of metal-oxide-semiconductor (MOS) transistors and the high confinement of plasmonic structures.

I will present an experimental demonstration of an ultracompact PlasMOStor, a plasmon slot waveguide field-effect modulator based on a transparent conducting oxide active region that can modulate plasmonic signal with high dynamic range (2.71 dB/μm) and low waveguide loss (~ 0.45 dB/μm).[3] In addition, I will present our recent experimental results on gate-tunable metasurface that enables dynamic electrical control of the phase and amplitude of the plane wave reflected from the metasurface.[4] A phase shift of π and ~ 30% change in the reflectance are achieved by applying 2.5 V gate bias, a basic requirement for electrically tunable beam-steering phased array metasurfaces.

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2. G. V. Naik, J. Kim, and A. Boltasseva, "Oxides and nitrides as alternative plasmonic materials in the optical range," *Opt. Mater. Express* **1**, 1090-1099 (2011).
3. H. W. Lee *et al.*, "Nanoscale Conducting Oxide PlasMOStor," *Nano Lett.* **14**, 6463 (2014).
4. Y. W. Huang*, H. W. Lee* *et al.*, "Gate-tunable conducting oxide metasurfaces," submitted to *Nature Nanotech.* (2015).