Empowering plasmonics and metamaterials technology with new material platforms

G.V. Naik1, J. Kim1, U. Guler1, N.K. Emani1, P.R. West1, N. Kinsey1, J.C. Ndukaife and A. Boltasseva1,2

1 Birck Nanotechnology Center, Purdue University, West Lafayette, 47907, IN, USA
2 DTU Fotonik, Technical University of Denmark, 2800 Kgs Lyngby, Denmark

In recent years, plasmonics [1] and metamaterials (MMs) [2] have seen an explosion of novel ideas and device designs. However, transforming these concepts into practical devices requires a significant amount of effort. The constituent materials in these devices play a crucial role in realizing useful and efficient devices. Similar to the way silicon shaped the nanoelectronics field, efforts toward finding the best set of materials for plasmonic and metamaterial devices could revolutionize the field of nanophotonics. As a potential solution, alternative plasmonic materials have recently gained significant attention [3, 4]. Metals, despite being essential components of plasmonic and metamaterial devices, pose many technological challenges toward the realization of practical devices - primarily due to their high optical loss, integration and fabrication limitations [3]. Hence, searching for an alternative to metals is vital to the success of future nanophotonic devices [4].

In this contribution, a brief survey of recent developments in the pursuit of better plasmonic materials will be provided. Several classes of materials including doped semiconductor oxides and intermetallics as potential alternatives to metals that provide low intrinsic loss, tunability and compatibility with standard semiconductor fabrication processes will be discussed.

For plasmonic applications, intermetallics (such as transition metal nitrides) and transparent conducting oxides nanoparticles enable strong localized surface plasmon resonances (LSPR) in the red end of the visible and in the near-infrared ranges, respectively [5]. Simple nanospheres of gold or silver would not be able to produce LSPR in these wavelength ranges. Thus, alternative plasmonic materials offer advantages in sensing and other applications where LSPR is used. For surface plasmon-polariton (SPP) waveguiding applications, calculations show that transition metal nitrides such as TiN and ZnN would perform nearly as good as gold, offering low cost, fabrication and integration advantages at the same time [5].

New materials as substitutes for noble metals could greatly boost the performance of many metamaterial devices and expand their application horizon significantly [4]. For example, TiN as an alternative plasmonic material could make the devices CMOS compatible. Also, the high melting temperature and hardness of TiN are very useful for applications such as thermal radiation engineering and energy harvesting [6]. New plasmonic materials such as TiN also enable better devices and exploration of new physics associated with them.

For example, we showed that new plasmonic materials outperform gold and silver by many orders of magnitude for non-resonant MMs such as hyperbolic metamaterials (HMMs) [7]. Hyperbolic metamaterials are extremely anisotropic materials that possess different signs of real permittivity in different directions [8]. These MMs exhibit unusual properties such as supporting the propagation of extremely high-k waves and possessing extremely large photonic-densities-of-states (PDOS) over a broad bandwidth [8]. These properties have been utilized in achieving sub-wavelength imaging and could lead to a new generation of light sources such as single photon guns [9]. A planar technique used in realizing HMMs involves stacking subwavelength thick alternating layers of metal and dielectric. Such metamaterial devices currently suffer from high losses, especially in the visible range, because of the undesirable properties of their metallic building-blocks. Conventionally, gold and silver are the only plasmonic materials used in such metamaterials. However, gold and silver pose many problems such as high loss, difficulty in making smooth and continuous ultrathin layers, and a lack of tunability. In addition, these metal building blocks are not compatible with high-temperature or thermal plasmonics, and are also not compatible with CMOS technology. Instead, we propose to use a metal/dielectric superlattice system composed of TiN as a plasmonic material that behaves as a hyperbolic metamaterial in the visible range and has higher figure-of-merit than silver- or gold-based systems.

Due to lower optical loss, easier fabrication and integration, new plasmonic materials such as transparent conducting oxides and transition metal nitrides can be good replacements for noble metals as plasmonic elements in the optical range for many plasmonic and metamaterial applications.

Acknowledgements. This work was supported in part by ARO grant 57981-PH (W911NF-11-1-0359), MRSEC NSF grant DMR-120923 and NSF "MetaPREM" Award 1205457.

References