Nanomechanical Control of Optical Antennas and Metasurfaces

Mark L. Brongersma[1]

1. Geballe Laboratory for Advanced Materials, Stanford University, Stanford, CA USA 94305

E-mail: brongersma@stanford.edu

Despite the many impressive advances on static metasurfaces, it remains very challenging to create ones capable of dynamically controlling complex optical light flows. If this were possible, it would unlock exciting new physics and important practical applications in computational imaging, display technologies, quantum communication, thermal emission management, and biochemical sensing. The realization of dynamic metasurfaces requires the development of nanostructures that not only strongly scatter light, but also offer large tunability in their optical response. One might imagine that metallic or high-index nanostructures could be good candidates as they support strong plasmonic and Mie-style optical resonances that allow them to serve as optical antennas. Unfortunately, such antennas display very weak tunability because of the limited magnitude of most electroabsorption and electrorefraction effects in metals and semiconductors. Fortunately, the optical responses of nanostructures are very sensitive to their relative position. As a consequence, the tuning of resonances can be accomplished very effectively by means of mechanical movement. In this presentation, I will discuss various approaches to move nanostructures with great control and repeatability at the nanoscale. These rely on the use of nanoscale electromechanical devices, surface acoustic waves, and mutable soft materials.

I will devote special attention to the plasmonic dimer, which is comprised of two closely-spaced metallic nanoparticles. The dimer has served as the prototypical system to study near- and far-field optical coupling of plasmonic structures. The understanding and engineering of such coupling is central to the design of metamaterials and nanophotonic devices. Most notably, the overlap of the near-fields in closely-spaced metallic particles can be used to controllably hybridize individual plasmon modes. This can lead to a desirable redistribution of optical fields and an intense light concentration. The extreme light confinement renders the dimer’s optical response very sensitive to minute changes in gap size and facilitates the observation of a variety of intriguing quantum effects. These findings naturally prompt the fundamental questions to what extent fields can be concentrated and resonances be tuned by mechanically moving particles. I will discuss several works from our group that demonstrate very large mechanical tuning of optical resonances (> 100 meV/nm) in the dimer and particles-on-mirror geometries for very small (~1 nm) gap spacings. Such gaps are at least 2 orders of magnitude smaller than the wavelength of light and these works indicate that the fundamental size limit of electro-optical modulators may need to be re-evaluated.

References

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