Resonant metaphotonics and metasurfaces

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Abstract: We review the recent advances in *nonlinear metaphotonics* of nanoparticles and metasurfaces empowered by optical resonances. We demonstrate a giant enhancement of the second-harmonic signal generated from silicon metasurfaces at guided-mode lattice resonances and quasi-bound states in the continuum. © 2023 The Author(s)

In metaphotonics, resonances play a pivotal role in enhancing nonlinear effects. Optical properties of metaphotonic structures, whether composed of individual nanoparticles or metasurfaces, are determined by the geometry of their units (meta-atoms) and material properties. Metallic nanostructures can host a variety of resonances, ranging from local surface plasmon resonances (LSPR) in individual nanoantennas to nonlocal lattice modes in plasmonic metasurfaces.

Compared to low efficiencies and losses in metallic structures, dielectric metasurfaces and nanoantennas provide an attractive low-loss platform for nonlinear metaphotonics. The main building blocks of dielectric metastructures are dielectric nanoparticles supporting vectorial Mie resonances. Dielectric nanostructured surfaces can also host optical bound states in the continuum (BICs), observed as quasi-BICs, with dramatically large quality factors (Q factors) from several hundred to tens of thousands. Common types of resonances in plasmonic and dielectric structures are shown in Fig. 1.

For nonlinear nanostructures, the phase matching is not applicable, and the frequency conversion efficiency is defined by the resonant characteristics such as coupling efficiency and mode Q factor. It was demonstrated recently that quasi-BICs with very large Q factors can boost the generation of the third harmonics by several orders of magnitude enabling ultrafast self-action effects in the non-perturbative regime. Also it was shown recently that silicon metasurfaces hosting quasi-BICs in the mid-IR wavelength range produce the generation of up to 11-th harmonics, as well as that individual AlGaAs nanoresonators can generate higher-order odd harmonics.

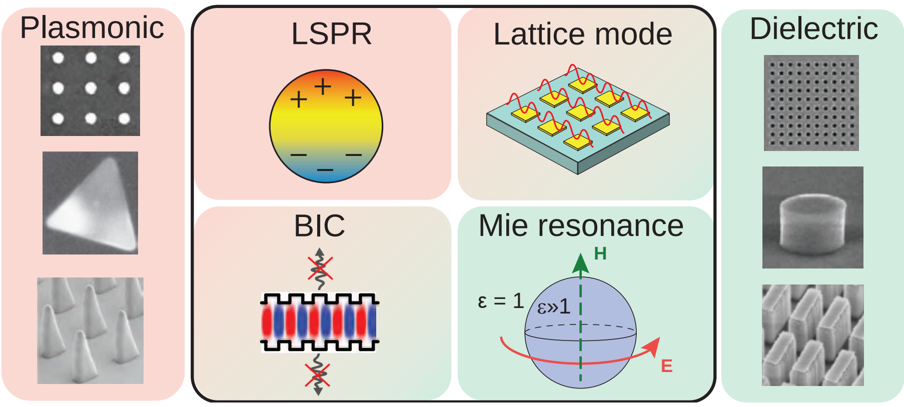

Fig. 1. **Optical resonances in metaphotonics.** Left: SEM images of plasmonic metasurfaces with lattice guided mode, LSPR, and BIC resonances. Middle: the main types of resonances in plasmonic (red), dielectric (green), and hybrid (gradient) metastructures. Right: SEM images of dielectric metastructures supporting guided-mode lattice, Mie, and BIC resonances.

As a specific example, here we demonstrate a giant enhancement of the second-harmonic generation (SHG) from resonant silicon metasurfaces. Our metasurface is composed of a square lattice of asymmetric meta-molecules consisting of bar dimers with a different width. We observe experimentally SHG and third-harmonic generation (THG) with the resonant enhancement of SHG by three orders of magnitude.