Nonlinear dielectric metasurfaces and oligomers: harmonics generation and all-optical switching

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Compact yet efficient nonlinear-optical devices are a cornerstone of modern photonics. Wave-mixing and all-optical switching processes are sought for in micro- and nanostructures as those effects pave the way for a new optics-based telecommunication and data manipulation paradigm [1]. Silicon photonics is believed to dominate the area: microring resonators, Raman lasers and other devices are readily available to be integrated into photonic circuits [2]. However, shrinking down the size of silicon-based devices was hardly considered feasible until it was recently realized that highly localized Mie-type modes can be excited in silicon nanoparticles [3]. Utilizing the Mie-type resonances in silicon nanospheres, nanodisks and other geometries is a promising strategy to achieve high nonlinear processes efficiencies at low mode volumes.

In this talk we review our recent investigations of nonlinear optical properties of silicon-based nanoparticles and metasurfaces. The nanostructures under study are distinguished by fundamental localized magnetic Mie-type resonances with mode volumes as low as $\lambda^3/100$. It is shown by third-harmonic generation (THG) spectroscopy and THG microscopy that effective third-order nonlinearities of silicon nanodisk arrays are two orders of magnitude larger than those of an unstructured bulk silicon slab [4]. Arranging nanoparticles in an oligomer (trimer) geometry provides for another degree of freedom in tailoring their nonlinear-optical response [5]. Finally, pump-probe measurement results of all-optical switching in silicon-based metasurfaces will be presented.

References

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Optical forces induced by Bloch surface waves on a one-dimensional photonic crystal

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Bloch surface waves (BSW) are surface electromagnetic modes that propagate in all-dielectric structures and provide large local field enhancement [1]. In our work, BSWs are shown to be a promising tool for optical manipulation of dielectric microparticles. Momentum of the BSW at a one-dimensional photonic crystal/water interface is experimentally demonstrated to be transferred to a 1-µm polystyrene microsphere located in the vicinity of the photonic crystal surface. As it is observed by means of optical microscopy, the interaction force generated by the BSW is large enough for particle localization near the surface and propulsion along the BSW propagating direction. To measure the force quantitatively, photonic force microscopy is used.

Photonic force microscopy technique is based on the determination of the particle displacement in an optical tweezers trap at an external force influence [2]. The experiment scheme and results of photonic force microscopy of the BSW are shown in Fig. 1. The measured force decays exponentially with moving off the surface at large distances, but there is a surprising diminution of the force at surface/particle gaps less than 150 nm. The maximum value of 0.25 fN at the exciting radiation intensity of 1.6 kW/cm^2 is observed at the BSW excitation resonance.

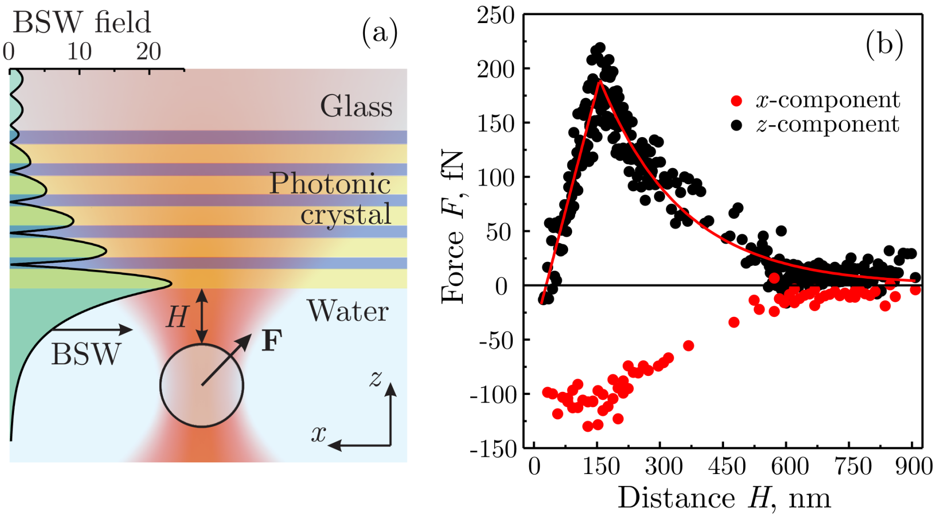

Fig. 1: (a) The experiment scheme. The calculated distribution of the incident BSW electric field amplitude is shown in green. (b) The x- (red dots) and z-coordinate (black dots) projection value of the measured force depending on the distance between the particle and the photonic crystal surface.

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Distributed feedback laser

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We consider lasing in one dimensional photonic crystal, which primitive cell consists of two layers: Maxwell–Bloch-like active layer and passive layer. It is shown that when lasing starts the effective dielectric structure loses its periodicity because the Bloch mode is not periodic. However, at the band-edge where the Bloch mode is periodic and its period is equal to the photonic crystal cell size, the distribution of electromagnetic field in photonic crystal becomes also spatial periodic. Besides, due to Borrmann effect electromagnetic field tends to concentrate in the passive or active layers of