Engineering nonlinearities in plasmonic nanorod metamaterials

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Abstract

Plasmonic metamaterials based on aligned nanorods provide an opportunity to engineer nonlinear optical response by controlling the interaction between plasmonic modes of individual nanorods as well as with active material embedded in the array. In this talk we will overview nonlinear optical properties of such bare and hybrid gold nanorod arrays in weak and strong coupling regimes as well as taking into account the effect of nonlocal electromagnetic interactions in the array.

Plasmonic metamaterials allow realisation of a large number of photonic and nanophotonic applications, including negative index engineering, superlensing, optical cloaking and passive and active integrated photonic circuitry. The rarely studied class of such metamaterials is based on plasmonic nanorod arrays [1—7]. They consist of metal nanorods (20—60 nm diameter, 40—80 nm spacing between rods, 50—500 nm length) attached to the substrate with their axes aligned perpendicularly to it. The nanorods can be free standing or immersed in dielectric, e.g., polymer matrix. They are inexpensive to fabricate over large areas [1,2,6].

Optical properties of such metamaterials are determined by strong interaction between plasmonic resonances of the individual nanorods and are due to collective plasmonic response of the nanorod ensemble. The resonant frequency of such collective plasmonic excitations and spatial variation of the associated electromagnetic field distribution can be designed by modifying the nanorod array parameters: size of the nanorods, their separation, permittivity of the metal and embedding dielectric matrix. Not only linear but also nonlinear optical properties of the nanords can be designed by adjusting geometrical parameters to invoke nonlocal effects to enhance nonlinearity [1,3] or by hybritising the metamatrials with nonlinear molecular species and engineering weak [5,6] or strong coupling regime [7] between molecular and plasmonic excitations.

In this talk we will overview the studies of nonlinearities in plasmonic nanorod metamaterials in various regimes and discuss applications in nanophotonic devices. Ultrafast nonlinear optical response of such metamaterials allows all-optical modulation of the optical properties with sub-picosecond time response at low intensities of control light and can be useful for designing the all-optical components of integrated nanophotonic circuits.

References

[1] G. A. Wurtz, R. Pollard, W. Hendren, G. P. Wiederrecht, D. J. Gosztola, V. A. Podolskiy and A. V. Zayats, Designed ultrafast optical nonlinearity in a plasmonic nanorod metamaterial enhanced by nonlocality, *Nature Nanotech*., vol. 6, p. 107, 2011.

[2] A. V. Kabashin, P. Evans, S. Pastkovsky, W. Hendren, G. A. Wurtz, R. Atkinson, R. Pollard, V. A. Podolskiy and A. V. Zayats, Plasmonic nanorod metamaterial for biosensing, *Nature Materials*, vol. 8, p. 867, 2009.

[3] R. J. Pollard, A. Murphy, W. R. Hendren, P. R. Evans, R. Atkinson, G. A. Wurtz, A. V. Zayats and V. A. Podolskiy, Optical nonlocalities and additional waves in epsilon-near-zero metamaterials, *Phys. Rev. Lett.*, vol. 102, 127405, 2009.

[4] G. A. Wurtz, W. Dickson, D. O'Connor, R. Atkinson, W. Hendren, P. Evans, R. Pollard and A. V. Zayats, Guided plasmonic modes in nanorod assemblies: strong electromagnetic coupling regime, *Opt. Express*, vol. 16, p. 7460, 2008.

[5] W. Dickson, P. Evans, G. A. Wurtz, W. Hendren, R. Atkinson, R. J. Pollard and A.V. Zayats, Towards nonlinear plasmonic devices based on metallic nanorods, *J. Microsc.*, vol. 229, p. 415, 2008.

[6] W. Dickson, G. A. Wurtz, P. Evans, D. O'Connor, R. Atkinson, R. Pollard, A. V. Zayats, Dielectric-loaded plasmonic nano-antenna arrays: a metamaterial with tuneable optical properties, *Phys. Rev. B*, vol. 76, 115411, 2007.

[7] G. A. Wurtz, P. R. Evans, W. Hendren, R. Atkinson, W. Dickson, R. J. Pollard, W. Harrison, C. Bower, A. V. Zayats, Molecular plasmonics with tunable exciton-plasmon coupling strength in J-aggregate hybridized Au nanorod assemblies, *Nano Letters*, vol. 7, p. 1297, 2007.

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