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Metamaterials with Gain[1]

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Nanoplasmonic metamaterials are the key to an extreme control of light and allow us to conceive materials with negative or vanishing refractive index. Indeed, metamaterials enable a multitude of exciting and useful applications, such as subwavelength focusing, invisibility cloaking, and "trapped rainbow" stopping of light. The realization of these materials has recently advanced from the microwave to the optical regime. However, at optical wavelengths, metamaterials may suffer from high dissipative losses owing to the metallic nature of their constituent nanoplasmonic meta-molecules. It is therefore not surprising that overcoming loss restrictions by gain is currently one of the most important topics in metamaterials' research. At the same time, providing gain on the nanoplasmonic (metamolecular) level opens up exciting new possibilities such as a whole new type of metamaterial nano-laser with a cavity length of about a tenth of the wavelength. The talk gives an overview of the state of the art of gain-enhanced metamaterials. Particular focus will be placed on nano-plasmonic metamaterials (such as double-fishnet metamaterials) with integrated laser dyes as gain medium. The successful compensation of loss by gain is demonstrated on the meta-molecular level. On the basis of a comprehensive, microscopic Maxwell-Bloch Langevin approach of spatio-temporal light amplification and lasing in gain-enhanced nanoplasmonic (negative-index) metamaterials a methodology based on the discrete Poynting's theorem is introduced that allows dynamic tracing of the flow of electromagnetic energy into and out of "microscopic" channels (light field, plasmons, gain medium). It is shown that steady-state amplification can be achieved in nanoplasmonic metamaterials. Finally, a complex spatio-temporal interplay of light-field and coherent absorption dynamics is revealed in the lasing dynamics of a nanoplasmonic gain-enhanced double-fishnet metamaterial.

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