Spatio-temporal modeling of lasing phenomena in plasmonic structures

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Nanoscale laser sources have attracted a great deal of attention recently, due to their fundamental interest and technological applications. Plasmonic nanostructures integrated with gain materials emerge as prominent platforms in which light-matter interactions are enhanced at the deep subwavelength scale, displaying ultrafast dynamics and low-threshold lasing action. This has motivated the experimental realization of plasmonic nanolasers based on metallic nanoparticles, stripes, or nanocavity arrays [1].

In this talk, we present our recent work on lasing action in plasmonic systems that incorporate optically pumped gain media. To that purpose, we introduce a novel theoretical framework, based on a time-dependent generalization of the finite element method (FEM), which allows us to track the spatio-temporal dynamics of the nanoscale nonlinear interaction of the highly-nonuniform electric field of plasmonic resonances and the quantum emitters composing the gain medium.

We focus on three different classes of plasmonic systems: First, we consider a plasmonic waveguide formed by a thin metallic film supporting long-range surface plasmons, placed between two Bragg mirrors acting as a feedback mechanism, and discuss the conditions for the building-up of self-sustained laser oscillations in such systems [2]. Next, we study metallic periodic structures (plasmonic crystals) supporting extended plasmonic resonances, such as periodic arrays of metallic nanowires and periodic arrays of subwavelength apertures milled in a metallic film, showing that the excitation of dark plasmonic resonances (via the gain medium) enables accessing the optimal lasing characteristics of this class of systems [3]. Finally, we discuss our recent results on lasing action in core-shell metallic nanoparticles. We study the evolution of the lasing dynamics when going from a spherical geometry to an elongated nanorod configuration, showing that there exists an optimal nanoparticle elongation that exhibits significantly improved lasing threshold and slope efficiency over those obtained for its spherical counterpart [4].

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