PROJECT II.4 THEORETICAL NANOTECHNOLOGY

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Research orientation: Theoretical study of the optical and elastic properties of periodic micro and nano structures, acousto-optic interaction.

MAIN RESULTS IN 2011

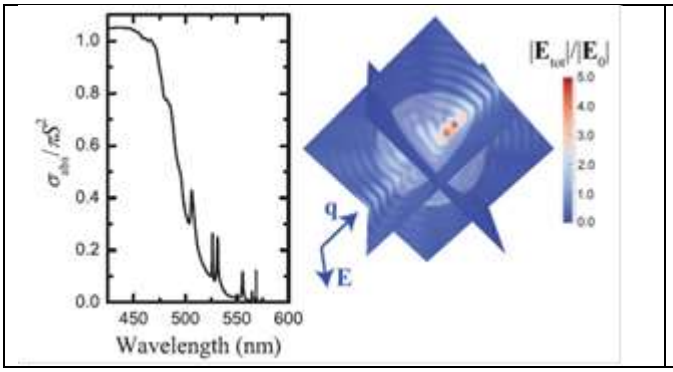
The main results obtained in 2011 within the different tasks of the project are given below.

A. PhoXonic architectures for tailoring the acousto-optic interaction

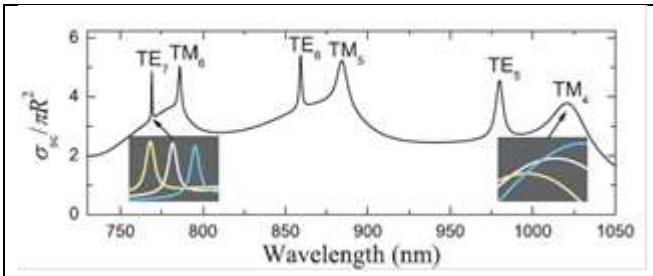
Artificial materials that have frequency regions where no wave propagation is allowed are known for both light (photonic crystals) and sound waves (phononic crystals). Structures that are simultaneous photonic and phononic (phoXonic) crystals were recently predicted theoretically. We have systematically investigated and proposed one-dimensional, two-dimensional and three-dimensional phoxonic crystals and studied cavities and waveguides in such environments. The simultaneous localization of light and elastic fields can give strong acousto-optic interaction and lead to new generation, miniaturized, acousto-optic devices.

B. Acousto-optic interaction in dielectric particles

Light modulation by acoustic phonons through the acousto-optic interaction has been used for several decades now in optical systems. We investigate spherical dielectric particles that exhibit simultaneously optical and acoustic resonances as potential candidates to enhance the interaction and achieve strong modulation of light through excitation of their acoustic eigenmodes. More specifically, we consider a spherical particle made of a chalcogenide glass material, subjected to excitation of its acoustic breathing modes by a femtosecond visible light pulse, and monitor the modulation of the optical scattering cross section over a broad wavelength range in the near infrared region. Our results reveal the occurrence of strong effects beyond the linear-response approximation, which lead to enhanced modulation of light by acoustic waves through multiphonon exchange mechanisms when both photons and phonons have a very long lifetime inside the particle.



A spherical particle of radius 500 nm made of a-As_2S_3: optical absorption cross section spectrum (left) and total electric field distribution upon illumination at a wavelength of 500 nm (right)

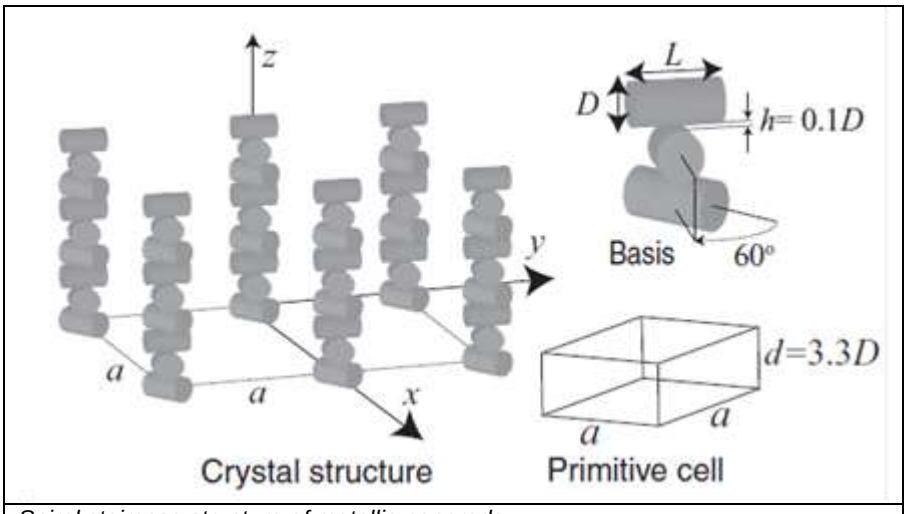


The optical scattering cross section of the a-As_2S_3 particle in the near-infrared region. The insets display the variation of the TE_7 and TM_4 Mie resonances, in a window of 5 nm, upon excitation of the fundamental acoustic breathing mode of the particle at a level corresponding to 0.1 nm (the curves on both sides of each resonance of the unperturbed particle correspond to snapshots at which maximum shift is obtained).

C. Plasmonic nanostructres

Metallic nanoparticle arrangements show a rich variety of optical phenomena, due to the excitation of surface plasmons. We have considered plasmonic crystals of metallic nanoshells and report on the occurrence and properties of photonic surface states in fcc crystals of metallic nanoshells.

Nanorod arrays in a spiral staircase arrangement shows interesting optical properties. The fact that a chiral arrangement of the atomic/molecular constituents (structural chirality) or an inherent chiral structure of the molecules themselves (molecular chirality) is responsible for the observed optical activity in some naturally occurring substances and materials has long motivated microwave studies on model systems of macroscopic bodies with helical symmetry. More recently, in the context of photonic crystals, three dimensional (3D) chiral dielectric structures were first proposed as artificial composite media that exhibit strong optical activity. Spiral staircase structures of metallic nanorods show negative refraction, as well as strong optical activity and circular dicroism.



Spiral staircase structure of metallic nanorods

Our study show that the combination of plasmonic modes and helical arrangement of the nanorods results in the formation of collective optical eigenmodes with a specific predominant circular polarization character, sizable polarization gaps, and negative group velocity bands that lead to negative refraction. Moreover, multilayer slabs of the given crystal exhibit strong optical activity and circular dichroism combined with reduced dissipative losses, which make the proposed structure potentially useful for polarization control applications in miniaturized optoelectronic devices.

PROJECT OUTPUT IN 2011

Publications in International Journals

1. "Nonlinear interactions between high-Q optical and acoustic modes in dielectric particles", G. Gantzounis, N. Papanikolaou, and N. Stefanou, Phys. Rev. B 84, 104303 (2011)
2. "Photonic surface states in plasmonic crystals of metallic nanoshells" C. Tserkezis, N. Stefanou, G. Gantzounis, and N. Papanikolaou, Phys. Rev. B 84, 115455 (2011)
3. "Spiral-staircase photonic structures of metallic nanorods" , Christofi, N. Stefanou, G. Gantzounis, and N. Papanikolaou, Phys. Rev. B 84, 125109 (2011)
4. "PhoXonic architectures for tailoring the acousto-optic interaction" , N. Papanikolaou, I. E. Psarobas, G. Gantzounis, E. Almpanis, N. Stefanou, B. Djafari-Rouhani, B. Bonello, V. Laude, A. Martinez Proc. of SPIE 8071 80710Z-1 (2011) doi:10.1117/12.886562
5. "Light modulation in phoxonic nanocavities" , N. Papanikolaou, I.E. Psarobas, N. Stefanou, B. Djafari-Rouhani, B. Bonello, V. Laude Microelectron. Eng. (2011), doi:10.1016/j.mee.2011.04.069
6. "Band gaps and waveguiding in phoxonic silicon crystal slabs" , Pennec, Y., Djafari Rouhani, B., El Boudouti, E.H., Li, C., El Hassouani, Y., Vasseur, J.O., Papanikolaou, N., Benchabane, S., Laude, V., Martinez, A. Chinese Journal of Physics, 49, p100-110 (2011)
7. "Simultaneous guidance of slow photons and slow acoustic phonons in silicon phoxonic crystal slabs" , Vincent Laude, Jean-Charles Beugnot, Sarah Benchabane, Yan Pennec, Bahram Djafari-Rouhani, Nikos Papanikolaou, Jose M. Escalante, and Alejandro Martinez Optics Express Vol. 19, Iss. 10, pp. 9690–9698 (2011)
8. "Fluorescence enhancement from plasmonic Au templates" , P. Petrou, I. Raptis, S. Kakabakos, Th. Speliotis, A. Gerardino and N. Papanikolaou Microel. Eng. in press doi:10.1016/j.mee.2011.02.073 , (2011)
9. "Multiple scattering calculations for layered phononic structures of nonspherical particles" , G. Gantzounis, N. Papanikolaou, N. Stefanou, Phys. Rev. B 83, 214301 (2011)