phd project

light interactions with nano-meta-materials

Metamaterials are understood as artificial media with their uncommon electromagnetic properties not available in nature. They were initially originated in microwaves at the end of the last century and subsequently, thanks to rapidly developing nanofabrication techniques, quickly adopted in optics. Metamaterials owe their uncommon properties to subwavelength details of their structures rather than to their chemical compositions. Structural units of metamaterials can be tailored in shape, size, position, orientation and material parameters. Therefore, overall structural composition of metamaterials can be conveniently tuned to achieve desired material - electromagnetic in the first place - properties.

Due to their unprecedented potential, metamaterials are now expected to open several new possibilities in searching for electromagnetic medium properties that are unavailable from naturally occurring materials. For example, within a range of microwave frequencies, a metamaterial composed from conducting wire and split-ring resonator elements of subwavelength dimensions was the first man-made structure expressing a negative index of refraction. Note that, as it was indicated by Veselago and Pendry in their seminal papers of 1968 and 2000, respectively, the negative refraction index implies also an all-angle negative refraction at a surface of an isotropic metamaterial. This phenomenon does not seem to be observed in nature at all, at least within some definite frequency range. Soon, the negative-index composites became the most prominent examples of a true nano-meta-material.

In electromagnetics, a refractive index is the square root of the product of relative dielectric permittivity and magnetic permeability of a material. It can be conceived that both these two medium parameters could be simultaneously negative within a certain frequency range. If such a double negative medium could be produced, then it is properly described by the negative index of refraction. During the last decade it has been proved that such artificial metamaterials can actually be produced in scientific laboratories. Since the introduction of such nanomaterials, known as the double negative (DNG) materials, and their subsequent structural modifications, in general now known as the negative-index materials (NIM), they have provided solid grounds for further fascinating research within the range of nanophotonics, nanoplasmonics and optoelectronics.

The research on electromagnetic properties of metamaterials, on their complex - linear and nonlinear - interactions with externally incident light wave packets, and on their various optoelectronic, photonic and plasmonic applications, is recently under a tremendous progress. More information on recent research on metamaterials, and on their principal inventors as well, may be found in the community perspective comments: *Pioneers in metamaterials: John Pendry and Victor Veselago*, written by Allan Boardman in Journal of Optics 13, 020401 (2011), and in publications referenced therein.

The idea of composing photonic structures from metamaterials, stimulated by expectations of their counterintuitive optical responses and exploitation of their other uncommon properties, has been under investigations only for a few years. Thus, many interesting phenomena are still waiting for exploration. What is the most straightforward way of research on the light-metamaterial interactions? It seems that the best way is to directly replace one dielectric component of any photonic structure by its metamaterial counterpart and to check, by theoretical analyses, numerical simulations and, finally, by direct experimental processes of nanovisualisation, what happens when such the replacement takes place. Always several new, counterintuitive outcomes appear.

A number of examples of such new phenomena can be found in publications within this range, from the metamaterial slab optical response yielding subwavelength imaging - commonly understood as the “super lens” action - through such the lens plasmon polaritonic realizations - obtained by the right choice of composite nanoparticle lattices - to the unpredictable deformations or even annihilation of an optical image - known, within transformation optics, as the “optical illusions”.

Topics investigated recently in the Research Group of Nanophotonics are well suited to this goal, as they are covering several phenomena of optical interactions with photonic, plasmonic and nano-meta-material structures, such as:

- spin and orbital angular momentum of photons,
- cross-polarization coupling at nanostructures,
- higher-order HG and LG optical wave packets,
- vortex generation, propagation and splitting,
- normal modes of planar photonic structures,
- nonlinear propagation of beams and pulses,
- optical Kerr effects, solitons and bistability,
- plasmon concentrators and switches,
- resonances at nano-meta-structures,
- near field optical nanovisualisation,
- optical trapping of nanoobjects.

One example of the research outcome of this type - on optical vortices - is given below. More detailed description of these topics, already published in journals on optics and photonics, can be found at the www page: http://www.ippt.gov.pl/~wnasal/.

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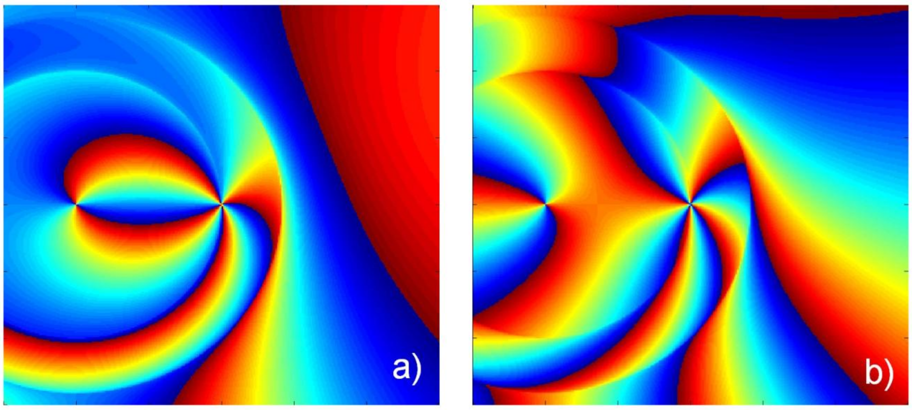
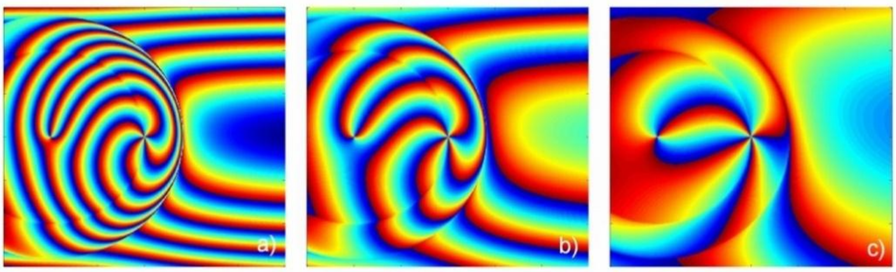
optical vortex excitation, propagation and splitting photon angular momentum conservation at a dielectric isotropic interface

excitation and splitting of optical vortices induced by cross-polarisation of beam components of elegant Laguerre-Gaussian beams; beams of the left and right circular polarization are incident obliquely on a planar interface; beam radii are sub-paraxial of the order of one wavelength

from: W. Nasalski, Bull. Pol. Ac.: Tech, 58, 141 (2010)



Incidence of the $eLG_{2,4}$ beams of CL and CR polarization. Phase distribution of the reflected beam at the interface (a) for CL polarization of the incident beam and CR polarization the reflected $eLG_{3,2}$ beam component with the total topological charge equal to 4-2, (b) for CR polarization of the incident beam and CL polarization the reflected $eLG_{1,6}$ beam component with the total topological charge equal to 4+2. In both cases of the incidence (CL and CR) polarization the total (spin + orbital) angular momentum per the reflected photon is equal to that of the incident photon: 3ħ (a) and 5ħ (b).



Vortex phase evolution during propagation of the reflected CR polarized beam of the $eLG_{3,2}$ shape. The beam phase spectrum is shown in the interface plane for different incident beam waist positions placed at z/z_D=: (a) -1.0, (b) -0.5, (c) -0.1; z/z_D=0.0 means a beam waist position at the interface, as shown in the above fig. (a); z and z_D state the propagation distance and the diffraction length of the reflected eLG beam, respectively.