NEW PROPAGATION PHENOMENA IN OPTICAL METAMATERIALS

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Optical metamaterials are artificial substances composed of nanoscale-size structural units (metamolecules). Since these units are small compared to the wavelength of light, the material can be considered as optically homogeneous. Typically, metamolecules have non-trivial shapes and a size > 50 nm. As a result, the refractive index (n) and wave impedance (Z) in such materials depend on the propagation direction of the field. We have developed a theoretical basis for treating the interaction of optical beams with such metamaterials. The method is based on a vectorial angular-spectrum representation [1] and a technique to evaluate n and Z for any propagation direction in the material [2].

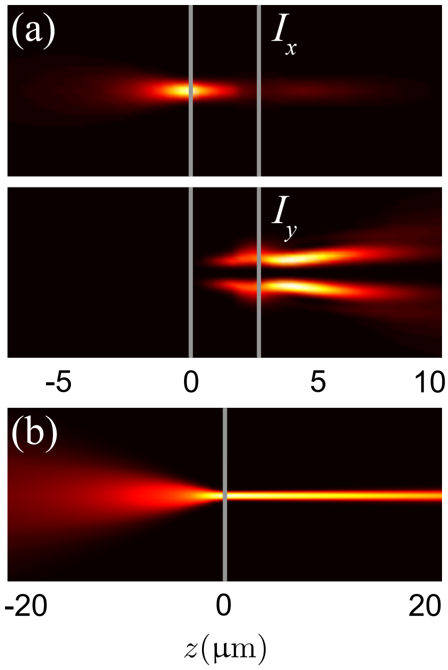

Figure 1: Influence of spatial dispersion on beam propagation. Polarization conversion is shown in (a) and diffraction compensation in (b).

We use the aforementioned methods and explore two new optical phenomena, polarization conversion by spatial dispersion and divergence-free propagation of optical beams. We show that the first phenomenon leads to the absence of polarization eigenmodes as well as the wave parameters n and Z for certain propagation directions in the material. Figure 1a illustrates the generation of an orthogonal polarization in a beam propagating through a metamaterial slab of silver discs. The original linear polarization of the beam is chosen to be unaffected by the optical anisotropy. The second phenomenon is observed in a metamaterial with a flat isofrequency profile of the propagation-angle-dependent refractive index. Figure 1b demonstrates the divergence-free propagation of an optical beam in a metamaterial designed for this purpose [3]. In addition to suppressed optical diffraction, the material has a low surface reflectivity due to impedance-matching to the surroundings. The phenomenon can be used to create wide-angle optical coatings, planar laser resonators, novel waveguides and aberration-free flat imaging elements.

[1] V. Kivijärvi, M. Nyman, A. Karrila, P. Grahn, A. Shevchenko and M. Kaivola. New J. Phys. **17**, 063019 (2015).
[2] A. Shevchenko, P. Grahn, V. Kivijärvi, M. Nyman and M. Kaivola. J. Nanophoton. **9**, 093097 (2015).
[3] V. Kivijärvi, M. Nyman, A. Shevchenko and M. Kaivola. J. Opt. (2016) (in press).