Cross-polarization coupling – an abandoned property of 3-dimensional photonic crystals

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Abstract

In this paper we demonstrated experimentally and theoretically that the rotation of the polarization of incident light is intrinsic property of 3-dimensional photonic crystals. An opal crystal was used as an example. This effect should be taken into account when discussing polarization anisotropy of finite size photonic crystals because its magnitude is comparable to the transmission/reflectance in co-polarized light.

1. Introduction

Standard characterization of 3-dimensional photonic crystals (PhCs) includes measurements of transmission and reflectance spectra in linear polarized light in the zero diffraction order. In particular, this applies to opal-based PhCs, which consist of closely packed dielectric spheres. The discussion of the polarization anisotropy of the opals optical properties remained a popular topic over the past decade. This anisotropy was considered in conjunction to the Brewster angle, the critical angle of diffraction and symmetry of PhC eigenmodes. Only recently the attention was drawn to mixing of polarizations that occur in opal crystals [1,2]. Thus, if the birefringence is an intrinsic property of an opal lattice in spite of its cubic syngony, it may essentially change the existing understanding of the way how an opal crystal processes the incident light.

The opal lattice obeys face-centred cubic (fcc) symmetry for which no cross-polarization coupling is expecting. Nevertheless, ellipsometry reveals the polarization rotation for the normal incidence of light, which was explained by the lattice distortion [3]. In contrast, numerical modelling reveals polarization mixing in ideally packed opals. Based on the dispersion argument, this effect was attributed to diffraction [1]. Recently, we suggested that polarization rotation occurs, if light couples to two closely spaced modes possessing a slightly different field distribution. The beating of these propagating modes results in the gradual rotation of the polarization vector of outgoing light and in the periodical variation of the polarization mixing rate along the opal slab when the thickness is increased [4]. In this work we demonstrate that the polarization activity of the opal PhC is an essential component of its optical properties and it has a non-diffraction origin.

2. Experimental technique

Thin film opals were prepared by crystallization in a vertically moving meniscus under acoustic noise agitation [5] of PMMA spheres with a diameter of 558 nm. The film thickness was 13µm, which corresponds to 23 (111) planes. Transmission and reflectance spectra in the zero diffraction order were measured under illumination with a collimated beam of white light in ss-, pp- and sp-polarizations using different combinations of polarizer and analyser. These spectra were measured as a function of the light incidence angle and of the azimuth orientation of the plane of light incidence for several values of the incidence angle. Numerical simulations of transmission and reflectance spectra of the ideal fcc package of dielectric spheres with parameters matching that of experimental opal were performed using the Fourier Modal Method [6].

3. Results and discussion.

The reflectance and transmission bands in the cross-polarized spectra obtained as a function of the incidence angle (Fig.1) follow the dispersion of diffraction resonances in co-polarized reflectance/transmission spectra. The maximum of the cross-polarized coupling is observed around the directions of an avoided band crossing. This is an indication of binding of the polarization activity to eigenmodes of the opal lattice.

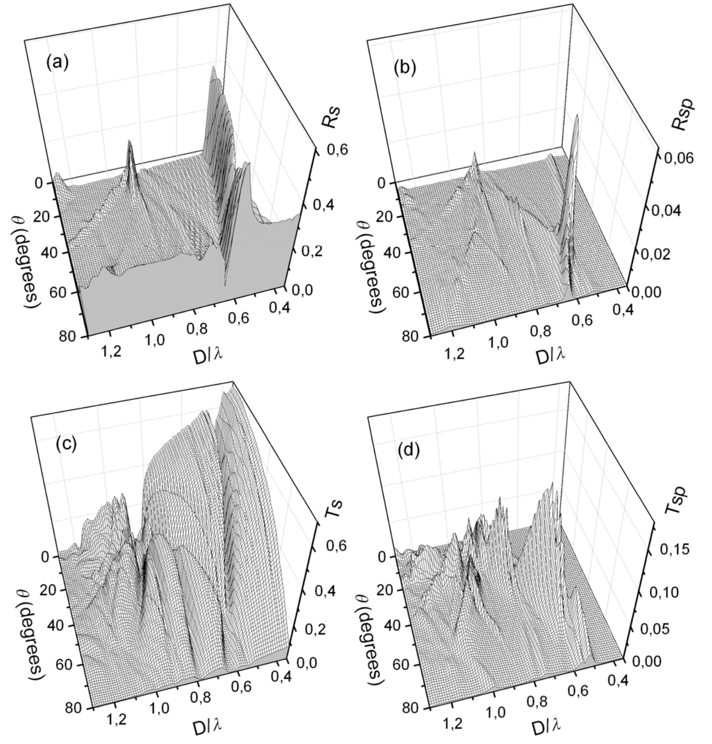

Fig.1. (a,b) Experimental reflectance and (c,d) transmission spectra in ss- and sp-polarizations, respectively.

The clear evidence of one-by-one correspondence between eigenmode dispersion and cross-polarized coupling is the azimuth dependence of the transmission in the co- and cross-polarized light (Fig.2). The major features of the experimental spectra are reproduced surprisingly well by the simulated transmission of the ideally-packed fcc lattice of spheres (Fig.3). This agreement can be considered a proof of the intrinsic nature of a cross-polarized optical response of the opal lattice.

However, the magnitude of the polarization mixing is not proportional to the magnitude of the diffraction resonances. This discrepancy points to the crucial role of additional conditions on the appearance of a cross-polarized signal. We argue that these essential ingredients are the symmetry of eigenmodes and the details of the photonic bandgap structure. In particular, the field distribution in the eigenmode should be uniform enough to assign it a polarization state. That is why the patterns of cross-polarized transmission and reflectance differ from that of co-polarized ones. The maximum of the mixing rate is achieved in the ΓLW section of the Brillouin zone.

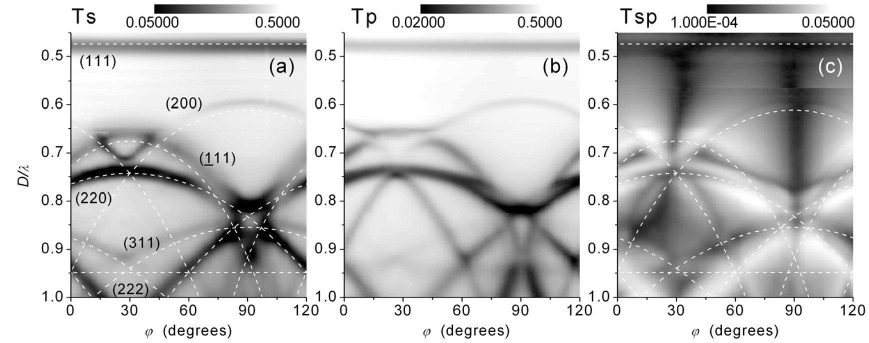

Fig.2. Azimuth-dependent transmission of the opal film in (a) ss- , (b) pp- , and (c) sp-polarized light as a function at $\theta = 30^o$. The 120^o fragment of azimuthal dependence contains all possible spectral features. Dashed lines show the dispersions of Bragg resonances. They are labelled with Miller indices of the corresponding fcc crystal planes.

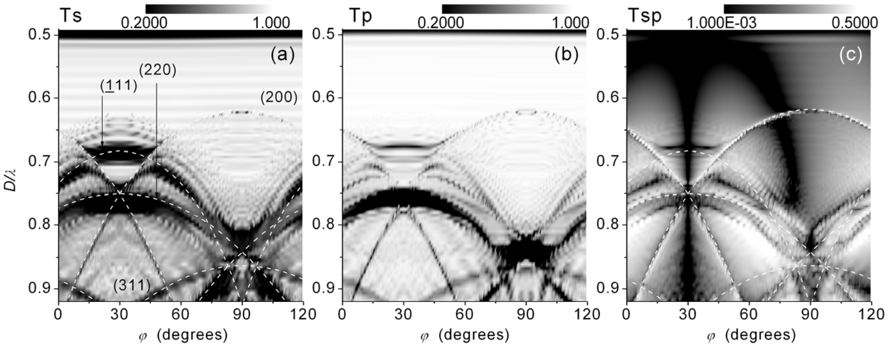

Fig.3. (a,b,c) Numerically simulated spectra of zero order transmission in ss-, pp- and sp-polarized light, respectively, at $\theta = 30^o$. Dispersion curves are the same as in Fig.2.

4. Conclusion

The rotation of the polarization vector occurring when light is passing through a finite size 3D PhC leads to polarization mixing in the outgoing light. The magnitude of the cross-polarized signal can approach that of the co-polarized signal. The rotation rate is a complex function of the symmetry of eigenmodes, their propagation direction and interaction as well as of the crystal thickness.

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