ABSTRACT

Photonic crystals (PCs) attract much attention, first of all, due to the prospects of their application in optoelectronics and photonics. The specific feature of these materials is the periodic variation of their permittivity in one, two, or three dimensions with a spatial periodicity comparable with the light wavelength. In the band gap of a PC with a lattice defect, i.e., with a broken periodicity, the transmission bands with controllable position and transmittance are formed. In this case, light is localized in the defect region, which leads to an increase in the light wave intensity inside the defect layer.

The possibility of manipulating by the photonic band structure using external factors is extremely important for many applications. It is well-known that liquid crystals exhibit the high sensitivity to external fields and strong anisotropy of the permittivity. An interesting type of liquid crystals is cholesteric liquid crystals (CLCs), which exhibit all the properties of PCs and form a special class of chiral PCs.

New opportunities for governing light occur in one-dimensional PCs with the nanostructured metal-dielectric defect layers. The occurrence of the effective permittivity resonance was predicted for a nanocomposite consisting of metal nanoparticles dispersed in a transparent matrix, whereas the optical characteristics of the initial materials have no resonance features. The position of the resonance localized in the visible spectral range depends on permittivity of the initial materials and concentration and shape of nanoparticles.

At present, the surface properties of PCs evoke great interest. In particular, a special type of localized electromagnetic states excited at the normal incidence of light called the optical Tamm states (OTSs) has been intensively investigated. This phenomenon is used in various devices, including sensors, solar cells, and lasers. Therefore, the experimental and theoretical study of the OTSs in tunable PC structures based on CLCs is very promising.

The aim of this study was to theoretically investigate the spectral and polarization properties of PC structures based on CLCs.

In the course of this work, the following problems were solved:

(i) Study of photonic defect modes in a CLC combining an isotropic nanocomposite layer with the resonant dispersion and twist defect.

(ii) Study of the localized optical states in the structure “CLC – quarter-wave plate – metal”.

(iii) Study of the localized optical states in a structure formed by two oppositely twisted CLC layers and a metal.

(iv) Study of the localized optical states in a system consisting of the defect-containing CLC and metal.

The obtained results were reported at several international and domestic scientific conferences.

The importance of the conducted fundamental investigations of spectral and polarization properties of PC CLCs with inclusions of resonant nanocomposites and anisotropic materials is determined by the significantly broadened possibility of controlling the parameters of the photon energy spectrum, and transmission, reflection, and absorption spectra of CLCs and the high potential of these materials for application in new optoelectronic and photonic devices.

Our study disclosed a number of important spectral and polarization features of the PC structures based on CLCs. New opportunities of controlling light with the high efficiency were demonstrated, which are characteristic of only the chiral media.

Defect modes in a CLC combining a nanocomposite layer with the resonance dispersion and the twist defect were investigated. The spectral properties of such a structure are caused, first of all, by the resonance character of the nanocomposite effective permittivity and its significant dependence on the filling factor. The phase shift of a cholesteric helix is a nontrivial control technique, which can only be implemented in chiral PCs. The transmission spectrum of the investigated structure can be effectively tuned by changing the direction and value of the twist defect.

We proposed three new models containing a CLC and a metallic layer, where the localized optical states are observed. The change in the wave polarization upon reflection from the metal and the specific polarization properties of CLCs require a phase-changing element to be embedded in the structure. Such an element can be the anisotropic quarter-wave layer, oppositely handed CLC, or defect CLC. The mechanism of light localization in the investigated systems was explained in detail. It was demonstrated that the transmission spectra of light propagating in the forward and backward directions for a model containing the quarter-wave element are different; i.e., we observe the transmission anisotropy. Therefore, the investigated structure can be used as a polarization optical diode based on the surface photonic modes.

The possibility of effective control of the transmission spectrum was demonstrated for all the investigated systems. Manipulation by the transmission peak position via changing the CLC helix pitch using external fields and other parameters characteristic of specific systems were investigated.