Reflection Spectra of 1D Photonic Crystals Based on Aluminum Oxide

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Abstract—Optical properties (transmission and reflection) of 1D photonic crystals (PCs) based on mesoporous anodic aluminum oxide with the lattice periods of 188 and 194 nm are investigated. The experimentally measured reflection spectrum is compared in its first bandgap region with the theoretical dependence obtained from the dispersion relation for the 1D PC. Angular dependence is established for spectral positions of bandgaps in the 1D PC. A possibility of using mesoporous aluminum-oxide-based 1D PCs as narrow-band filters, narrow-band mirrors, and refractive sensors of molecular compounds is analyzed.

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1. INTRODUCTION

New types of optical elements with adjustable optical properties are currently in demand, which arouses interest in investigation of photonic crystals (PCs) [1−4], media with the permittivity varying in space with a period allowing Bragg diffraction of light. A 1D PC consists of alternating layers with two different refractive indices \( n_1 \) and \( n_2 \). The reflection spectrum of this crystal has regions in which strong reflection of electromagnetic radiation from the crystal surface is observed. These regions are called bandgaps. Their spectral positions depend on the PC parameters, such as the lattice period and the refractive indices.

An important example of PCs is a mesoporous structure with pores tens of nanometers in diameter [4−6]. Earlier optical properties of globular PCs made from silica (\( \text{SiO}_2 \)) spheres densely packed into a face-centered cubic lattice were investigated [7−10]. Recently a method for producing mesoporous 1D PCs by electrochemical etching of aluminum has been developed [6, 11], and PC films of mesoporous anodic aluminum oxide were obtained with the lattice period depending on the etching regime and varying in the range of 100 to 300 nm. The goal of this work was to investigate optical properties of these films with different periods and to analyze their angular dependences with a view to controlling their reflection spectra.

2. EXPERIMENT

Thin (25 \( \mu \text{m} \)) aluminum oxide films produced by electrochemical etching were investigated. Figure 1 shows photos of the films taken at different angles of incidence and observation of radiation.

At the center of sample 1 (Fig. 1(a), region 3) there is a PC film of mesoporous aluminum oxide. It is surrounded by a circular layer (see Fig. 1(a), region 2) of an identical film on an aluminum substrate. The rest of the sample surface (see Fig. 1(a), region 1) consists of pure aluminum. Figure 1(b) illustrates transparency and homogeneity of the film in the visible spectrum.

Wideband radiation transmission and reflection spectra of the PC films under discussion were investigated. Figure 2 shows the transmission spectra of wideband radiation from a xenon lamp for two types of films with different lattice periods.

As is evident from Fig. 2, there are sharp minima in the film transmission spectra in the regions of the first and second bandgaps. For sample 1, the transmission minima correspond to the wavelengths of 574 and 295 nm, and for sample 2 they correspond to the wavelengths of 548 and 282 nm.

Mirror reflection of the wideband xenon lamp radiation from the surface of the PCs was investigated at different angles of incidence \( \theta \). As the angle of inci-
Fig. 1. (a) Surface of the mesoporous photonic crystal film based on anodic aluminum oxide at different angles of observation of reflected radiation: aluminum surface (1), surface of the photonic crystal film etched on aluminum (2), and surface of the photonic crystal film (3); and (b) a text seen through the transparent photonic crystal film.

Fig. 2. Wideband radiation transmission spectra of samples 1 (a) and 2 (b).

Fig. 3. Dependence $\lambda_B^2 = 4a^2n_{eff}^2 - 4a^2\sin^2\theta$ for samples 1 (a) and 2 (b).

The difference of the wavelengths at the reflection and transmission maxima in the observed spectra is due to the difference in the periods of samples 1 and 2. It is seen in Fig.3 that the square of the radiation wavelength, $\lambda^2$, linearly depends on $\sin^2\theta$ in accordance with (1).

Based on the data presented in Fig.3, we calculated the effective refractive index $n_{eff}$, refractive indices of the first $n_1$ and second $n_2$ PC media, and periods of the corresponding lattices for samples 1 and 2 (see the table).

The experimental layout with the mesoporous 1D PCs on the basis of aluminum oxide used as narrowband selective filters in detection of Raman scattering