OPTICAL PROPERTIES OF A COMPOSITE MICROCAVITY BASED ON MACROPOROUS SILICON

E.V. ASTROVA[1], G.V. LI[1], L.M. PORTSEL[1], D.A. KOSTENKO[1], T.S. PEROVA[2], S.A. DYAKOV[2], A. BALDYCHEVA[2], S.G. TIKHODEEV[3] AND N.A. GIPPIUS[3]

[1]*Ioffe Physical Technical Institute, RAS, Polytekhnicheskaya 26, St. Petersburg, Russia; E-mail: east@mail.ioffe.ru; Tel: (812) 292 79 57*

[2]*Department of Electronic and Electrical Engineering, Trinity College Dublin, Dublin 2, Ireland*

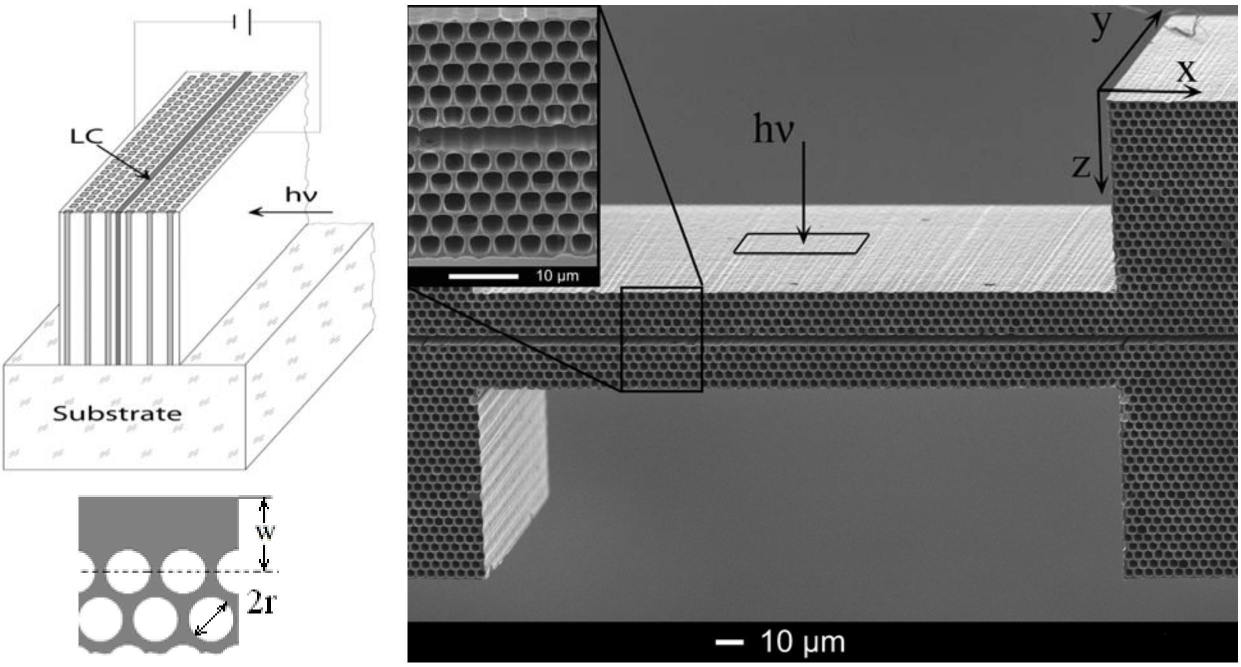
[3]*A. M. Prokhorov General Physics Institute, RAS, Vavilova 38, Moscow, Russia*

SUMMARY

The structure of a tunable composite microcavity for the mid-infrared spectral range based on a 2D photonic crystal is suggested. The structure of the cavity has been fabricated from macroporous slab with a defect in the form of a trench filled with a liquid crystal. Optical characteristics of the cavity were studied experimentally and theoretically. The part played by surface states and by light scattering on internal boundaries of pores was determined, and conditions for fabrication of a workable device were formulated.

1. INTRODUCTION

The goal of the study was to develop an electrically controlled microcavity in the form of a narrow slab of a 2D photonic crystal (PC) having at its center a trench defect filled with a liquid crystal (LC) (see scheme in the upper part of Fig. 1a). As the refractive index of the LC, n_{LC}, changes due to the electro-optical effect from 1.49 to 1.69, it would be expected that the resonance frequency should shift by 6%.



a b

Fig. 1. Structure of the microcavity: (a) schematic of an electrically controlled device and (b) SEM image of the Si structure.

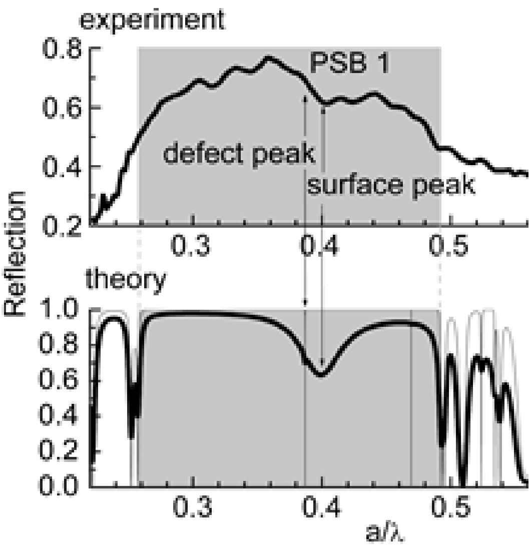
2. EXPERIMENTAL

To form the structure of the microcavity, the method of simultaneous etching of macropores and trenches [1] was chosen and the conditions providing the minimum distortion of the macropore shape and the smoothest side walls were determined [2]. Structures with a period a = 3.75 μm were fabricated, constituted by 5 rows of pores on both sides of the trench (Fig. 1b). The pore rows were oriented along the Γ-K direction, and the trench was filled with an E7 nematic liquid crystal.

The reflection and absorption spectra of both empty and LC filled structure were measured at wavelengths in the range 1.5-15 µm with a resolution of 8 cm^{-1} on a Fourier spectrometer equipped with an infrared microscope. Polarized light incident on the side wall of the structure had a rectangular aperture. Figure 2 shows an experimental reflection spectrum and two calculated dependences for the TE polarization in which the electric field vector of the light wave is perpendicular to the axes of the macropores. The spectra show a high-reflectance region (shaded by gray) corresponding to the lower photonic stop-band. This region has one broad dip with a minimum at $a/\lambda = 0.4$, which is due to a surface state.

3. RESULTS AND DISCUSSION

The PC slabs produced by simultaneous etching of macropores and trenches have an interfacial silicon layer with thickness *w* at outer boundaries of the structure (see lower part of Fig. 1a). As shown in [3, 4], this layer gives rise to surface states. Calculations by the scattering-matrix method [5] demonstrated that the spectral position of the surface mode depends on the thickness of the interfacial layer and the interaction of a surface state with the defect mode impairs the Q-factor of the microcavity.



Gray line in Figure 2 shows the calculated spectrum of the idealized structure, in which the surface state is not seen because of the extremely low amplitude. A narrow deep dip at $a/\lambda=0.385$ corresponds to the defect state. Apparently, this spectrum poorly agrees with that measured experimentally. To account for the loss for the Rayleigh scattering within the structure, a complex refractive index $n + ik$, where $n = 3.42$ and k is the extinction coefficient, was attributed to silicon. Doing so made it possible to perform a fitting. This procedure demonstrated that the best agreement between the calculation and experiment is achieved at $k = 0.02$ and filling factor $r/a = 0.43$ (black line in the lower spectrum of Fig.2). Thus, k can be used to evaluate the loss in a real structure.

Fig. 2. Reflection spectra of the composite microcavity for TE-polarized light.

Numerical experiments [6] have shown that, on making k larger, the amplitude of the defect state decreases and that of the surface mode increases, and, as a result, only the surface peak is seen in the experimental spectrum.

CONCLUSION

Hence follows that, in designing and fabricating a microcavity, appearance of a surface state in the photonic stop-band should be avoided, especially if its spectral position is close the cavity frequency. To this end, it is necessary that the thickness of the interfacial silicon layer *w* should be sufficiently small and the technological limitations should be complied with. With both these circumstances taken into account, there should be $0.45a \leq w \leq 0.55a$. In addition to the absence of surface states, the workability of a cavity is determined by the amplitude and Q-factor of the defect mode. Analysis shows that at the loss level characteristic of the fabricated structures, i.e., at $k = 0.02$, the number of periods in Bragg mirrors on both sides of the trench should be ≤3.

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