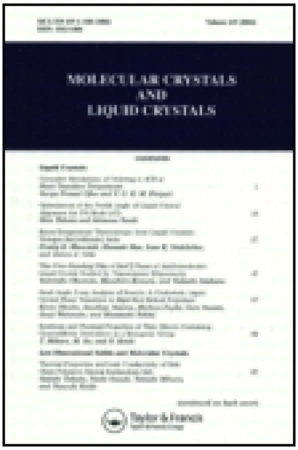

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Photonic Band Effect in Ordered Polystyrene Particle Layers

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Version of record first published: 24 Sep 2006

Mol. Cryst. Liq. Cryst., 2000, Vol. 349, pp. 5-8
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Photonic Band Effect in Ordered Polystyrene Particle Layers

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Quasi two-dimensional (2D) photonic band structures have been investigated on ordered polystyrene particle layers by means of polarized transmission spectra for oblique incidence of light. The results are discussed in terms of quasi-2D photonic band effect.

Keywords: quasi-2D photonic crystal; photonic band effect; polystyrene microparticles

INTRODUCTION

The concept of photonic bands for photons in specific dielectric media called photonic crystals is an optical analogue of the electronic bands in semiconductors, where the periodic variation of dielectric constant in the dielectric media plays the role of periodic electrostatic potential for electrons in semiconductors. Because of potential use of characteristic photon modes in photonic crystals, much efforts have been made on the various fabrication methods of photonic crystals and on their characteristic optical properties as well [1].

Photonic crystals investigated in the present study are 2D layers of submicron microsphere particles (latex) in the form of hexagonally ordered array on the surface of glass substrate. Such layer is regarded as ``quasi-2D" photonic crystals in the sense that the Bloch wave-like photon modes propagating within the layer have a finite lifetime due to the leakage of electromagnetic energy outside of the layer [2], in contrast to a ``real 2D" system such as an ordered array of parallel dielectric or air rods with infinite length. Nevertheless, the detailed studies on the ``quasi-2D" system are useful for the elucidation of fundamental properties of photonic crystals. The relative easiness in preparation of well ordered particle layers facilitates detailed studies of characteristic optical spectra associated with the photonic band effect [3].

In this paper, we report recent experimental results of polarized transmission spectra measurements on the hexagonally ordered polystyrene layers with various particle sizes. By plotting the spectral features as a function of photon energy and incidence angle, experimental dispersion curves of the quasi-2D photonic band modes have been successfully obtained.

SAMPLES, EXPERIMENTAL PROCEDURE AND RESULTS

The samples of ordered monolayers of polystyrene particles have been made by Nagayama method [3] using particles of diameter d=0.5~1.0 μm with diameter dispersion $\Delta d/d \leq 10^{-3}$. By adopting an improved procedure [4], the size of hexagonally ordered regions became sufficiently large to allow accurate measurements of transmission spectra. In order to change the photon wave vector along the Γ-M direction, the samples were rotated around the axis connecting the centers of the second nearest neighbor particles, while for the wave vector in the Γ-K direction the rotation axis was taken along the direction connecting the centers of adjacent neighbors. The respective measurements were made for the S and P polarized lights in the range of incidence angle θ from $-30°$ to $30°$ every degree.

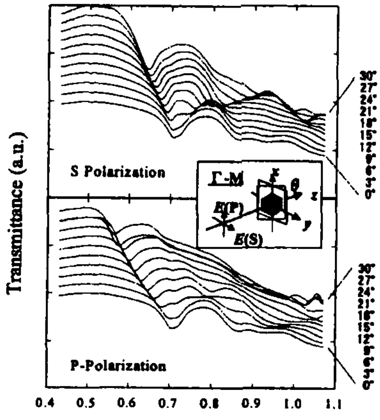

FIGURE 1: Polarized transmission spectra of ordered polystyrene particle layers (d=980nm).

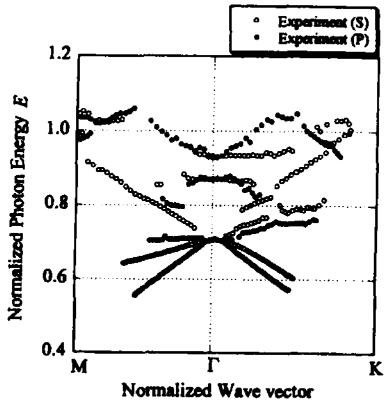

FIGURE 2: Experimental quasi-2D photonic band structures obtained from the transmission spectra.

Typical examples are shown in Fig. 1, for the S and P polarized spectra with the parallel component of the photon k-vector upon the layer plane oriented in the Γ-M direction. The abscissa is the normalized photon energy $E=\sqrt{3}d/2\lambda$. Similar spectra were also measured for the k-vectors parallel to the Γ-K direction. Each spectral feature (mostly minimum) for photon energy E corresponds to a quasi-2D photonic band mode at E and $k=(\omega/c)\sin\theta$. By plotting these experimental points, we can obtain experimental dispersions in the photonic band structure, as shown in Fig. 2. Note that the lowest band appearing at about E=0.72 is degenerated at the Γ point, but it is split into several polarized components in both Γ-M and Γ-K directions. Such splittings are also seen in the higher bands, though not so prominent as the lowest band. Evidently, these splittings are attributed to the photonic band effect. It should be also noted that the lowest band is P-polarized and shows a negative dispersion near the Γ-point, like the valence-bands of usual semiconductors. Similar features of the quasi-2D photonic band structures have been reported recently on silica microsphere layers [5] and on a 2D array of 2 μm polystyrene particles fabricated by micro-manipulation [6]. These detailed features in the experimental photonic band structures presently obtained can be analyzed by the theoretical calculation using the vector spherical-wave expansion method [2]. Such calculation and comparison with the present experimental results are now in progress, and will be reported shortly.

Acknowledgments

This work was supported by the Grant-in-Aid for Scientific Research from The Ministry of Education, Science, Sports and Culture, Japan. One of the authors (RS) acknowledges the Grant from Hayashi Memorial Foundation for Female Natural Scientists.

References

[1] For a review, J. D. Joannopoulos, R. D. Meade and J.N. Winn : *Photonic Crystals* (Prinston University Press, New York, 1995).
[2] K. Ohtaka, Y. Suda, S. Nagano, T. Ueta, A. Imada, T. Koda,J. S. Bae, K. Mizuno, S. Yano and Y. Segawa : Phys. Rev. B **61,** 5267 (2000).
[3] R. Shimada, A. Imada, T. Koda, T. Fujimura, K. Edamatsu, T. Itoh, K. Ohtaka and K. Takeda: Mol. Cryst. Liq. Cryst., **327,** 95 (1999).
[4] S. Matsushita, T. Miwa, D. A. Tryk and A. Fujishima : Langmuir **14,** 6441 (1998).
[5] T. Yamazaki and T. Tsutsui : Jpn. J. Appl. Phys., **38,** 5916 (1999).
[6] H. T. Miyazaki, H. Miyazaki, K. Ohtaka and T. Sato : submitted to J. Appl. Phys.