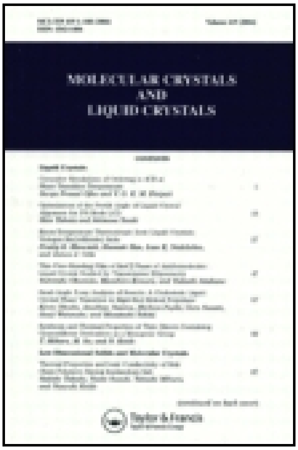

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

Self-Assembled Polystyrene Microparticle Layers as Two-Dimensional Photonic Crystals

Ryoko Shimada [a], Aya Imada [a], Takao Koda [a], Toru Fujimura [b], Keiichi Edamatsu [b], Tadashi Itoh [b], Kazuo Ohtaka [c] & Kenji Takeda [d]

[a] Department of Mathematical and Physical Sciences, Japan Women's University, Tokyo, 112-8681, Japan

[b] Department of Physical Science, Osaka University, Osaka, 560-8531, Japan

[c] Department of Applied Physics, Chiba University, Chiba-shi, 263-8522, Japan

[d] Tsukuba Research Laboratory, JSR Corporation, Tsukuba, 305-0841, Japan

Version of record first published: 24 Sep 2006

To link to this article: http://dx.doi.org/10.1080/10587259908026788

Mol. Cryst. Liq. Cryst., 1999, Vol. 327, pp. 95-98
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RYOKO SHIMADA[a], AYA IMADA[a], TAKAO KODA[a], TORU FUJIMURA[b], KEIICHI EDAMATSU[b], TADASHI ITOH[b], KAZUO OHTAKA[c] and KENJI TAKEDA[d]

[a]*Department of Mathematical and Physical Sciences, Japan Women's University, Tokyo 112–8681, Japan,* [b]*Department of Physical Science, Osaka University, Osaka 560–8531, Japan,* [c]*Department of Applied Physics, Chiba University, Chiba-shi 263–8522, Japan and* [d]*Tsukuba Research Laboratory, JSR Corporation, Tsukuba 305–0841, Japan*

(Received June 30, 1998; In final form July 15, 1998)

Optical properties of ordered polystyrene microsphere layers have been investigated and the results are discussed in terms of the two-dimensinal photonic band effect.

Keywords: self-assembled system; latex; photonic crystal; near-field optics

INTRODUCTION

When a dielectric medium has a periodic variation in the refractive index, the dispersions of electromagnetic waves (or photons) within the medium exhibit characteristic features similar to those in the electronic bands in semiconductors. The dielectric medium showing such features is referred to as a photonic crystal[1]. Intensive efforts have been made in order to examine novel optical properties of photonic crystals. Yet, due to the difficulty in the fabrication of photonic crystals with real materials, the present stage of study is still far from thorough understanding of the photonic band effect.

In this paper, we present some results on the optical properties of two-dimensional (2D) ordered layers of colloidal polymer microspheres, called latex. After method of sample preparation is briefly described, optical transmission spectra of the latex monolayers are demonstrated together with theoretical spectra based on a vector spherical wave method. Scanning near-field microscope (SNOM) observations are also reported.

Experimental procedures, results and discussions

The method of fabrication of ordered latex layers was similar to that by Nagayama[2]. The colloidal particles were self-assembled into an ordered layer by the attractive surface tension between the particles. The resulting layers were either stable hexagonal close-packed lattice or metastable square lattice. In the case of former structure, the lattice order is fairly good over a region of nearly 100 μm in size. The optical studies were made on hexagonal monolayers with particle diameters ranging from 5 to 0.3 μm.

When a monochromatic light is incident to a 2D photonic crystal, an electromagnetic (EM) field within and near the layer is represented by a superposition of spherical electromagnetic waves originating from each of dielectric spheres. When the wavelength of incident light is smaller than the diameter of dielectric spheres, the energy distribution of the field may be considerably localized within the spheres due to the temporal trapping of light within each spherical particle. Such a localization of light has been investigated in detail by Kuwata-Gonokami et al. for a dye-doped latex particle of several 10 μm in diameter[3].

In the 2D layers of latex particles, the EM field in the layers may be considerably delocalized because of the smaller sphere size and the strong inter-particle coupling of the EM field via the near-field optical effect. The latter effect is related with the formation of the 2D photonic band in a periodic array of spherical particles, as discussed by Ohtaka and Tanabe[4]. In order to examine the 2D photonic bands effect, we have measured transmission spectra of hexagonal latex monolayers with dif-

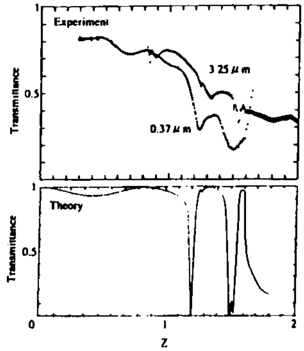

FIGURE 1. Experimental (a) and theoretical (b) transmission spectra of 2D spherical particle monolayers.

ferent particle diameters. The transmission spectra measured for normal incident light are shown in Fig.1(a) for typical samples with the particle diameter d = 0.37 and 3.25 μm. The relative intensities of transmitted light are plotted against the reduced photon energy (Z), that is the ratio of the particle diameter d to the wavelength λ. Theoretical spectrum calculated by the vector spherical wave method is also shown for the same parameter Z. Appearance of two minima at around $Z = 1.22$ and 1.53 is seen in both experimental and theoretical spectra, indicating that the concept of 2D photonic bands is able to well explain observed optical properties of the 2D latex monolayers.

The propagation of EM field in the real space can be investigated by using a scanning near-field optical microscope (SNOM)[6]. We demonstrate in Fig.2 the SNOM pattern for an ordered layer of latex particles (d = 1.0 μm). A part of particles (2 %) is replaced by the same size particles doped with fluorescent organic dye. The 457.9 nm light from an Ar-ion laser was injected from the tip of SNOM. The total fluorescent lights excited by the laser beam spot were collected by a detector placed on the opposite side of the layer. In the SNOM pattern shown in Fig.2 (inset), a bright spot corresponds to the emission from a fluorescent particle directly excited by the tip. A regular pattern is observed around this bright spot, indicating that a part of the EM energy injected into

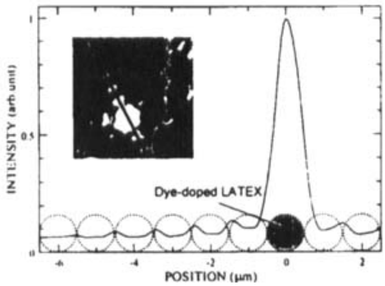

FIGURE 2. SNOM patterns of ordered latex layer (see text for detail).

the layer from the tip propagates between the particles toward a nearby fluorescent particle and is then emitted as the fluorescence light. The fluorescence intensity was measured along a straight line (see the inset). The result is shown by a solid curve in Fig.2.

From these results, we conclude that the EM energy propagates through some specific near-field modes (the 2D photonic bands) in the layer. The fluorescence intensity is high in the middle of the adjacent particles indicating an efficient transfer to the propagating modes, whereas the injected energy mostly penetrates through the layer when injected at the tops of particles. This is in a good agreement with the transmission SNOM observation[5].

This work was supported by the Grant-in-Aid for Scientific Research from The Ministry of Education, Science, Sports and Culture, Japan.

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