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Fabrication and Optical Characterization of Colloidal 3-D Photonic Crystals

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Abstract

3-D photonic band-gap structures are fabricated from dielectric colloidal polystyrene beads through a centrifuge method. The fabricated photonic crystals exhibit opalescent colors under white light and show a clear diffraction peak dependent on the incident angle of the light beam. Also the scanning electron microscope image was taken to verify the face-centered cubic crystal structure. Bragg's law and Snell's law are employed to describe the position of angle resolved diffraction peaks. It was shown that the optically deduced effective refractive index and lattice constants were in good agreement with the crystal structure identified by scanning electron microscope.

Keywords : Photonic Crystal, Collodal Particle

1. Introduction

Photonic crystal is an artificial structure possessing a periodic dielectric constant, with the length scale in the order of the wavelength of interacting electromagnetic wave [1]. Photonic crystals can exhibit three important phenomena, namely photonics band gaps, localized modes, and surface states. Because 1-D and 2-D photonic crystals are periodic only along one or two axes, the gaps and the bound states are limited to that direction, and the photonic band gap exists only in the plane of periodicity. 3-D photonic crystals are periodic along three axes, hence a complete photonic band gap irrespective of the propagating direction in the crystal for the electromagnetic wave with an energy falling in the stop band. Mono-disperse colloidal suspensions of silica or polystyrene spheres can self-assemble into close-packed 3-D photonic crystal structures at optical length scales, with excellent long-range periodicity [2].

2. Experiment

We fabricated 3-D opaline structures of polystyrene spheres (with diameter 175 nm - 528 nm) by a centrifuge method. A cell was constructed from two ITO glass substrates with the cell thickness of 12m. After an aqueous solution of mono-disperse colloidal dielectrics (polystyrene spheres from Polysciences) was inserted into the cell-gap, the centrifuge operation was performed to achieve the sedimentation of colloidal dielectrics. With this procedure 3-D opaline structures can routinely be obtained in 5-7 hours. The fabricated photonic crystals exhibit opalescent colors under white light and show a clear diffraction peak dependent on the incident angle of the light beam. In Fig. 1, the SEM images of the fabricated opal show a face-centered cubic (fcc) structure with the (111) face parallel to the surfaces of the substrate.

Bragg's law and Snell's law are employed to describe the position of angle resolved diffraction peaks shown in Fig. 2 [3]. The position of the first-order

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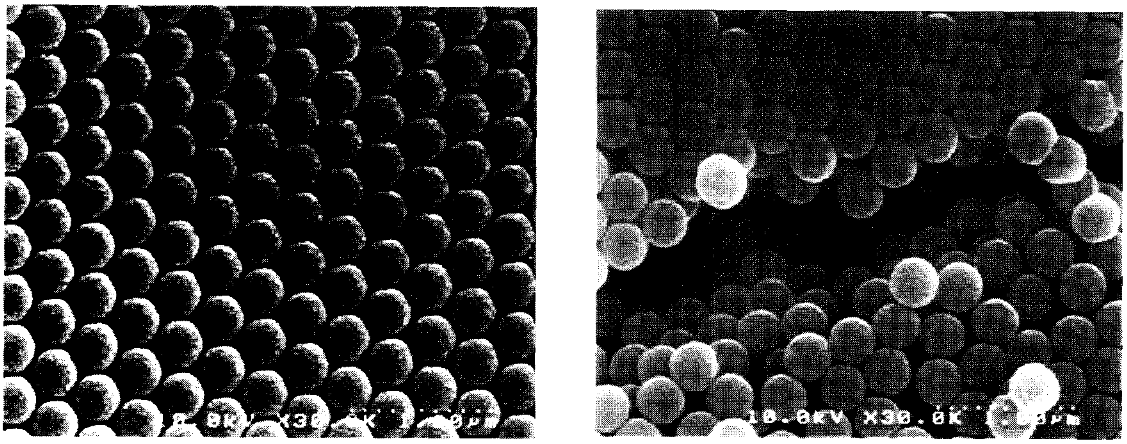

(a) (b)

Fig. 1. (a) SEM images of 3-D colloidal photonic crystal fabricated from 356 nm polystyrene spheres. (b) Cross sectional SEM images of 3-D colloidal photonic crystal fabricated from 356 nm polystyrene spheres.

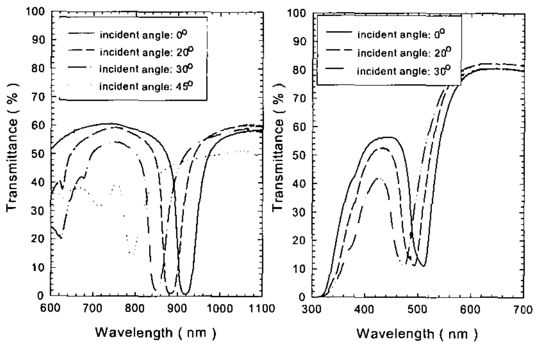

Fig. 2. Transmission spectra of 3-D colloidal photonic crystal of (a) 356 nm and (b) 175 nm at various angles of incidence.

Bragg diffraction peak could be calculated assuming the fcc lattice with the (111) face parallel to the substrate.

3. Results and Discussion

The effective refractive index of the fabricated photonic crystals was deduced from the volume fraction of the polystyrene spheres, air and water, and compared with a model description. It was shown that the deduced effective refractive index and lattice constants were in good agreement with the crystal structure identified by scanning electron microscope.

The colloidal photonic crystal has an advantage of forming 3-D photonic band gap structure, even the index contrast is rather low when compared with semiconductors. The reason why the photonic band gap survives is that the number of fcc layers are large enough to guarantee an optical diffraction.

4. Conclusions

In summary, we demonstrated an experimental fabrication of colloidal 3-D photonic crystal structure. Snell's law was employed to identify the lattice structure of the resulting photonic crystal, confirming fcc structure.

Acknowledgments

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