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Fabrication and Linear & Nonlinear Optical Characterization of Photonic Crystals

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1-D photonic band-gap structure is identified in a cholesteric liquid crystal system. The optical transmission spectrum is measured and compared with the theoretical analysis. Nonlinear transmission is measured near the band edge. Also 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.

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. Photonic crystals can exhibit three important phenomena, namely photonics band gaps, localized modes, and surface states.

A cholesteric liquid crystal cell was fabricated possessing 1-D photonic band gap structure. From the measurement of the linear absorption spectrum of the cell, the existence of a band gap was identified. The center of band gap was located at 1.08 eV (1143 nm) with the gap width of 0.1 eV (100 nm). The propagation of light in the cholesteric liquid crystal was analyzed by Berreman's 4×4 matrix method. Based on the linear absorption spectra, the dispersion of the principal refractive indices along the parallel and perpendicular direction of the molecule was determined. At the wavelength of 1064 nm, the linear refractive indices were found to be 1.631 and 1.476 along the parallel and perpendicular directions of the molecule.

A Q-switched Nd:YAG laser (1064nm) was employed to investigate the nonlinear optical changes in the position and width of photonic band gap. With the incident angle of 30 degrees, the right edge of the band gap (when plotted in wavelength) fell on the wavelength of 1064 nm. As the laser intensity was increased to 320 MW per squared cm, the transmission decreased from 0.51 and 0.47, corresponding to an 8% change. The nonlinear transmission change was analysed numerically by Berreman's 4×4 matrix method with the incorporation of Kerr nonlinearity in the optical response of the molecules forming choleteric liquid crystal. The changes in the refractive indices long the parallel and perpendicular directions were 3.46 and 1.51 times 10 to the minus 10 (squared cm per Watt), which is about 3 orders of magnitude larger than a typical third order nonlinearity of organic molecule. The enhancement is presumably from the increase of the density of states near the band edge of the photonic band gap. The analysis showed that the changes in the position and width of band gap are 0.02 eV and 0.03 eV at the laser intensity of 320 MW per squared cm. This observation opens the possibility of optical tuning of band gaps in 1-D photonic crystal structures.

We also fabricated 3-D opaline structures of polystyrene spheres (with diemeter 175nm ~ 528nm) by a centrifuge method. A cell was constructed from two ITO glass substrates with the cell thickness of 12 μm. After an aqueous solution of monodisperse 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 Figure 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.

Fig. 1 SEM images of 3-D colloidal photonic crystal fabricated in 12 μm thick cell from 356 nm polystyrene spheres.

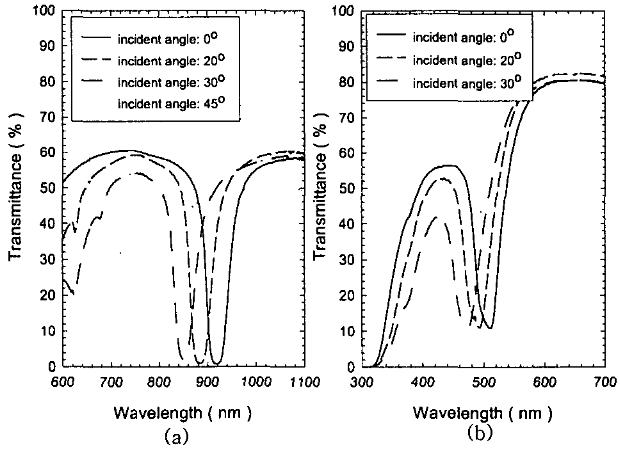

Fig. 2 Transmission spectra of 3-D colloidal photonic crystal of (a) 356nm and (b) 175nm at various angles of incidence.

Bragg's law and Snell's law are employed to describe the position of angle resolved diffraction peaks shown in Figure 2. The position of the first-order Bragg diffraction peak could be calculated assuming the fcc lattice with the (111) face parallel to the substrate.

$$\lambda_{max} = d_{111} a(n_{eff}^2 - \sin^2\phi)^{1/2} = 2(2/3)^{1/2} a(n_{eff}^2 - \sin^2\phi)^{1/2}$$

with a the lattice constant, ϕ the incident angle, f packing fraction, and $n_{eff} = n_{sphere} \times f + n_{void} \times (1-f)$ the effective refractive index. 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.

참고 문헌

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