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Modification of photonic crystal effect from few monolayers prepared by convective deposition with and without vibrating assistance

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Abstract

Photonic crystal effect can be observed in regular pattern thin film and an efficient inexpensive thin film fabrication method, which be able to control number of monolayers, is convective self-assembly. In this work, the film was prepared by polystyrene nanoparticle with particle sizes of 930, 500 and 310 nm. The few monolayer films were coated by convective deposition technique with fixed blade and slowly moving substrate with and without vibrating substrate. The optical properties of nanoparticle self-assembly were investigated by reflection spectrum analyzer embedded in microscope for nearly normal incident measurement. The spectrum angle depending on incidence and detector were also examined in co-rotational optical setting. The observed phenomena can be described by Bragg diffraction at various incident angle. The optical responses of self-assembly of 500 and 310 nm particles exhibited the photonic crystal effects in the green and blue color, respectively. It was found that the self-assembly nanoparticle usually provided a hexagonal closed packing. However in vibrational deposition, the polystyrene spheres can create the pattern of face centered cubic. This leads to the modification of photonic crystal effect shift on the thin film prepared with vibration. In addition, the self-assembly of 930 nm particles can show only the grating diffraction effect with various angle but the Bragg diffraction cannot be observed due to the detection limitation of visible light range.

Keywords: Photonic crystal effect; Convective deposition; Polystyrene nanoparticles; Bragg diffraction; Grating diffraction

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1. Introduction

Photonic crystal are materials with periodic dielectric constant. These materials can exhibit photonic band gap (PGB) when the electromagnetic waves propagates through them. This optical phenomena are compared with electronic band gap in solid state such as semiconductor. Photonic band gap is described by the Bloch's theorem which state that wave function of electrons in periodic potential can be written in combination of periodic function and plan waves, but photon is explained instead of electron. There are many applications of photonic crystal; such as waveguide [1], polarization splitters [2] and micro light wave circuits. [3] Thus, the photonic crystals have gained great interest for few decades. Photonic crystals are obtained with various methods; namely, vertical [4] or droplet [5] depositions. However, the potential technique which manipulates thickness and efficiently uses a solution is convective deposition. This method is physically moving substrate which is coated by nanoparticles and fixed blade. The convective deposition has been popular technique to fabricate particle-assembled thin film. Example of creating self-assembled colloid microlenses in order to optimize light extraction of LED, [6] modifying surface in microfluidic devices for cell capture [7] and macroporous membrane. The nanoparticles are driven from meniscus to forming region by evaporation flux, and packed by capillary force that is greater than Van der Waals, Brownian and Coulomb forces. The particles arrays have excellent packing for large particles about more than 900 nm. The small particles tend to aggregate and form highly rough surface. However, using vibration-assisted convective deposition [10] can decease an aggregation of small particles and also increase an overall packing density.

In this work, we study photonic effect from convective deposition films with and without vibrated glass slide which has a hydrophilic surface by isopropyl alcohol (IPA) washing. Three sizes of polystyrene dispersed in water, matching 310, 500 and 930 nm, were used to deposit. The condition of coating not only oscillated, but changed speed of moving substrate. Then we investigated the results with Bragg and grating diffraction. Grating diffraction reflects from surface while, Bragg diffraction occurs from crystal plane.

2. Experiment

In experiment, a glass microscope slide was fixed at angle of 45 degree which impinges on deposition with small gap over substrate. The substrate attached on linear motor is cleaned by acetone with 15 min., and washed by IPA to create hydrophilic surface. Then, the suspension of polystyrene nanoparticle which was vortexed and sonicated in cool water to make a good dispersion is dropped with 10 μL at angle between blade and substrate. Polystyrene nanoparticle dispersed in water (Thermo Scientific), there are three sizes such as 310, 500 and 930 nm. The fabrication was carried out in room temperature (about 24-25 °C) and humidity around 55%. Dragging velocity was range of 5-8 μm/s, and frequency was 40 Hz in case of vibration.

Colloidal packing films were analyzed by light reflection which are described by grating diffraction and Bragg diffraction. In crystalline material characterization, X-ray diffraction is a key to identify substances which occurs from diffraction of beams between plans. By this concept, the nanoparticle self-assembly has a response to specific wavelength that can determine packing structure. Behavior of light reflection is described by Bragg diffraction that is

$$2d\sin(90-\theta) = m\lambda \quad (1)$$

Where d and $\theta(\theta = \theta_i = \theta_r)$ are space between planes and angle of incident which equals to reflection angle, respectively. Moreover, lightwave reflected from pattern of nanoparticle arrays on surface is diffracted in multiband which provide the orders of diffraction (m). That is explained by formula of grating diffraction [9] which is

$$d(\sin\theta_r - \sin\theta_i) = m\lambda \quad (2)$$

where θ_i and θ_r are angle of incident and reflection.