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The fabrication of full color P(St-MAA) photonic crystal structure on polyester fabrics by vertical deposition self-assembly

Guojin Liu,[1] Lan Zhou,[1] Yujiang Wu,[1] Cuicui Wang,[1] Qinguo Fan,[1,2] Jianzhong Shao[1]
[1]Engineering Research Center for Eco-Dyeing and Finishing of Textiles, Ministry of Education, Zhejiang Sci-Tech University, Hangzhou 310018, China
[2]Department of Materials and Textiles, University of Massachusetts Dartmouth, North Dartmouth, MA 02747, USA
Correspondence to: Z. Lan (E-mail: lan_zhou330@163.com) and Jz. Shao (E-mail: jshao@zstu.edu.cn)

ABSTRACT: Three-dimensional (3D) photonic crystals with face-centered cubic structure were successfully fabricated on soft polyester fabrics via vertical deposition self-assembly, with monodisperse P(St-MAA) microspheres prepared by soap-free emulsion copolymerization. The resultant polyester fabrics exhibited bright structural colors through the well-ordered photonic crystal microstructure without any chemical dyes and pigments. The tunable structural colors across the whole visible region confirmed by reflectance spectra could be adjusted by controlling the diameters of the microspheres and viewing angles, and this was consistent with the law of the Bragg diffraction. The resultant polyester fabrics also presented some favorable properties including double-sided coloration effect, clear fabric texture, and soft fabric handle. The structural coloration by vertical deposition self-assembly of P(St-MAA) photonic crystals may provide a new strategy for textile coloration without using chemical colorants, and have a potential to reduce the pollution in the current textile dyeing and printing processes. © 2014 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2015**, *132*, 41750.

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INTRODUCTION

In textile industry, the main way for textile coloration is to attach colorants of dyes or pigments onto fibers, yarns, and fabrics on dyeing and printing processes. However, many creatures in nature show bright colors arising from special physical structures, referred to as structural colors,[1,2] exhibiting high brightness, high saturation, less discoloration, and iridescent effect (color changes with the viewing angle).[3,4] The formation of structural colors does not require any chemical colorants, and it is actually a visual perception to the selectively reflected light by a special physical structure interacting with incident light, such as dispersion, scattering, interference, and diffraction.[5,6] Nowadays, the structural colors originated from three-dimensional (3D) photonic crystals with photonic band gap in the visible and near infrared region have aroused much interests.[7,8]

The strong interest in photonic crystals stems from their potential to confine and control the propagation of light owing to the existence of photonic band gap, a range of frequencies in which light is forbidden to exist within the bulk of the photonic crystals, and is dependent on the crystal lattice and period.[9,10] If the photonic band gap falls into the visible light range between 380 and 780 nm, the visible light of specific wavelengths is not allowed to propagate in the photonic crystal structure, and thus being selectively reflected. Then, the structural colors would be produced on the surface of periodic photonic crystals. Therefore, it is convinced that Bragg diffraction is the theoretical basis of structural color produced by photonic crystal structure.

Recently, colloidal self-assembly has been explored widely and demonstrated as a simple and inexpensive approach to fabricate 3D photonic crystals, which can also be named as colloidal crystals.[3] A variety of methods by which assembling of spherical colloids into crystalline lattices has been successfully demonstrated, with notable examples including sedimentation in a gravitation field,[11,12] self-organization via the forces of electric fields, [13,14] and the flow of gas or liquid,[15,16] and crystallization through attractive capillary forces caused by solvent evaporation,[17] among which the vertical deposition method originated in capillary force provides a relatively simple and effective approach to fabricating high-quality colloidal crystal structure. In the vertical deposition method, a substrate is first immersed vertically into a suspension containing monodisperse colloidal microspheres. During the evaporation of the solvent, the surface of the solvent moves down and the film deposits onto the substrate during the decline of the solvent surface.[12]

In the last few years, the structural colors of photonic crystals have fostered a host of potential applications: inkless printing,

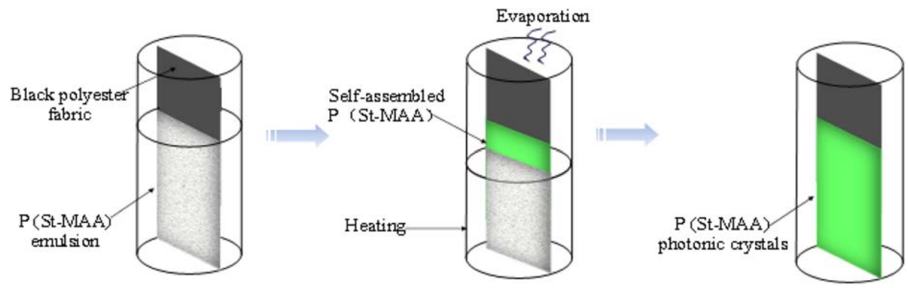

Figure 1. The schematic diagram of vertical deposition method for P(St-MAA) colloidal microspheres on polyester fabrics. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

reflective flat display, gas sensing, paints, photonic papers, cosmetics, and so forth.[18–20] In particular, the popular self-assembly procedures to fabricate photonic crystals on a solid substrate,[21] such as glass, silicon, and silicon nitride, have been well developed. However, the research related to photonic crystals on textiles to produce structural colors was rarely reported. Compared to the smooth, compact, and hydrophobic surfaces of solid substrates, textiles are of more complicated surface appearances, such as rougher and more fluctuant surfaces, many gaps among fibers, yarns, and so forth. In the previous research, our group has successfully fabricated photonic crystal structures of polystyrene (PSt) on polyester fabrics by gravitational sedimentation assembly and obtained brilliant structural colors[22]; however, the study on constructing photonic crystals on fabrics by vertical deposition has not been reported.

In this article, the monodisperse P(St-MAA) colloidal microspheres with perfect sphericity and controlled sizes were synthesized by soap-free emulsion copolymerization, and the photonic crystals of face-centered cubic (fcc) structure on polyester fabrics were achieved by vertical deposition self-assembly. The photonic crystals exhibited brilliant and monochromatic colors on textile fabrics and exhibited various structural colors by controlling the diameters of the colloidal microspheres and the viewing angles.

EXPERIMENTAL

Reagents and Materials

Styrene (St, A.R. grade, Yongda Reagent Factory, Tianjin, China) and methacrylic acid (MAA, A.R. grade, Kemiou Chemical Reagent Factory, Tianjin, China) were purified by distillation under reduced pressure. Ammonium persulfate (APS, A.R. grade, Yongda Reagent Factory, Tianjin, China) was used without further purification. Deionized water (>18 MΩ cm, Millipore Milli-Q) was used for the whole experiments. Nitrogen (98%, Jingong Specialty Gases, Hangzhou, China) was used as received from the laboratory. Black polyester plain weave fabric was bought from the local market.

Synthesis of Monodisperse P(St-MAA) Colloidal Microspheres

Batches of monodisperse P(St-MAA) microspheres with diameters in the range of 180–350 nm were prepared by soap-free emulsion copolymerization.[23] The size of the P(St-MAA) microspheres produced in this method is highly dependent on the different concentrations of St, MAA, and APS. The syntheses were carried out in a four-necked round-bottomed flask equipped with an inlet of nitrogen gas, a reflux condenser, a thermometer, and a mechanical stirrer. With one sample as an example, the procedure used was outlined as follows: 20 g of St, 3 g of MAA, and 195 g of H_2O were added to the four-necked round-bottomed flask. Nitrogen gas was then slowly bubbled through the resulting two-phase system and the mixture commenced to be mechanically stirred vigorously. When the mixture was heated to 70°C, 0.1 g of APS dissolved in 5 g of H_2O was introduced into the reactor. The reaction was maintained at 70°C for 8 h. The whole reaction was carried out in nitrogen atmosphere with mechanical stirring at around 350 rpm. The resulting colloidal suspension of P(St-MAA) microspheres was then filtered through a glass wool plug to remove any large agglomerates and then stored in polyethylene terephthalate plastic bottles for later use. When the parameters of the polymerization were changed, P(St-MAA) microspheres of different diameters can be prepared.

Fabrication of Photonic Crystals on Polyester Fabrics by Vertical Deposition

Photonic crystals were fabricated by a vertical deposition method on a black plain woven polyester fabric cleaned by ultrasonic in deionized water. First, after an ultrasonic treatment for 10 min, the colloidal suspension of P(St-MAA) microspheres was diluted to 1 wt % with deionized water. Then, a piece of polyester woven fabric was vertically placed in a glass bottle which was subsequently filled with the diluted microsphere suspension as shown in Figure 1. Finally, the polyester fabric with the diluted microsphere suspension was located in a vacuum drying oven at a constant temperature of 60°C with a relative humidity of 40–60% for more than 72 h dependent on various deposition rates of colloidal microspheres. After drying the sediment, water in the colloidal suspension was evaporated and a solid structure of well-ordered P(St-MAA) photonic crystals on polyester fabrics was obtained.

Characterization

Particle Size and Monodispersity. The particle size and monodispersity of P(St-MAA) microsphere were determined by dynamic light scattering (DLS) on a Malvern laser particle sizes analyzer (Nano-S, Malvern, England), and gauged from average diameter and particle dispersion index (PDI), respectively. It is noted that the P(St-MAA) colloidal suspension was diluted approximately 1000-folds with Milli Q water before taking measurement.[24]

Surface Morphology. The surface morphology of the P(St-MAA) photonic crystal structure on black polyester fabrics was

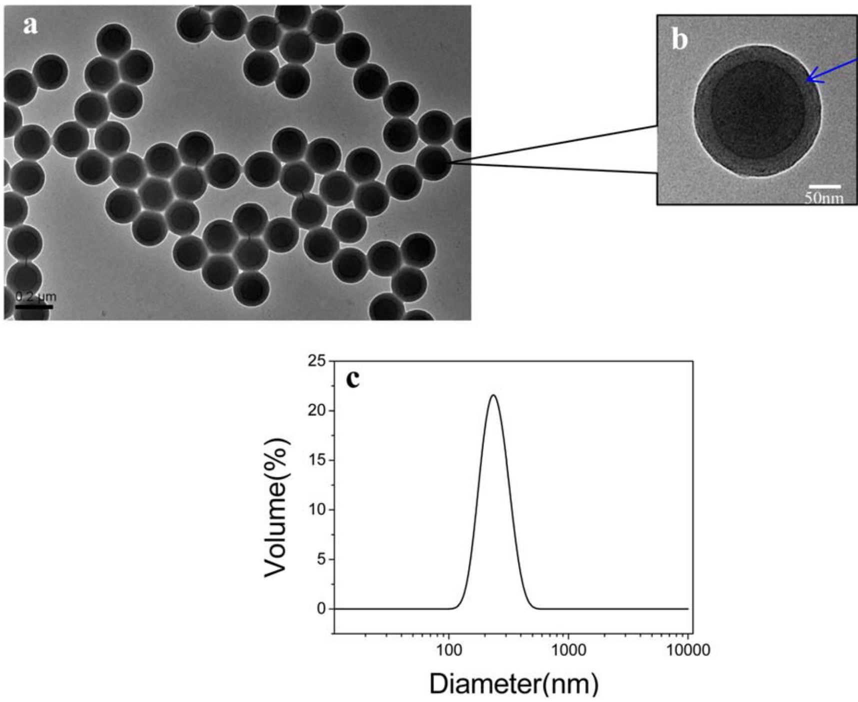

Figure 2. Typical TEM image and diameter distribution of P(St-MAA) microspheres: (a) typical TEM image of P(St-MAA) microspheres with a diameter of 210 nm; (b) high magnification TEM image of (a); and (c) diameter distribution of the P(St-MAA) colloidal microspheres of (a). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

observed by a field emission scanning electron microscopy (FESEM, ALTRA55, Germany) and a 3D video microscope (KH-7700, HIROX, Japan). All FESEM images were collected at an electron gun with accelerating voltage of 1 kV. In addition, the surface microstructure of the P(St-MAA) colloidal microspheres was also observed by a transmission electron microscope (TEM, JEM2100, Japan).

Reflectance Spectra. The reflectance spectra of structural colors on polyester fabrics were recorded over the range 400–700 nm on a UV–Vis Spectrometer (Lambda 900, PerkinElmer, USA). It should be noted that the reflectance spectra were measured at normal incidence.

Structural Color and Iridescence. The structural colors of P(St-MAA) photonic crystals on black polyester fabrics were observed by a digital camera (EOS600D, Canon, Japan) and a 3D video microscope (KH-7700, HIROX, Japan), at normal incidence. The iridescence of structural colors was recorded by a digital camera (EOS600D, Canon, Japan) and a multiangle spectrophotometer (MA98, X-Rite, USA) with colorimetric illuminant of D65 and colorimetric standard observer of 10°. The MA98 multiangle spectrophotometer is an intelligent, hand-held tool based on the reflection measurements, and it can provide the images, $L^*a^*b^*$ values, and reflectance spectra of the samples under various viewing directions. The measurement geometries were as follows: the sample was directionally illuminated at 45° from the normal, and the aspecular viewing angles in plane were at −15, 15, 25, 45, 75, and 110°; the secondary illumination was at 15° from the normal, and the aspecular viewing angles in plane were at −15 and 15°. The intensity of reflectance spectra measured by this multiangle spectrophotometer was in the range of 0–400% and the reflectance data reported were in agreement with the ASTM E2539-08[25] (http://www.packaging-network.com/doc/identifying-the-proper-instrument-geometry-for-measuring-metallic-inks-0001); (http://www.xrite.com/documents/literature/en/L10-001_Understand_Color_en.pdf.); (http://www.xrite.com/documents/manuals/en/MA98–500_Multi-Angle_User_Guide_en.pdf).

RESULTS AND DISCUSSION

Monodispersed Core–Shell Colloidal Microspheres of P(St-MAA)

The colloidal microspheres with uniform size and high degree of sphericity play a vital part in optical properties of photonic crystal materials. Therefore, the employment of a monodisperse sample is central to the self-assembly of these colloidal microspheres into homogeneous, crystalline arrays with large domain sizes.[11] Figure 2(a) shows a typical TEM photograph of the P(St-MAA) colloidal microspheres. It was observed that those P(St-MAA) colloidal microspheres were spherical in shape and monodispersed in size with a core–shell structure in which PS domains are located on the core of the colloidal microspheres, and a thin shell of 10–20 nm rich in poly(methacrylic acid) with carboxyl groups anchors upon the surface of colloidal microspheres dependent on the differences of polarity and hydrophilicity between St and MAA[26–29] as shown in Figure 2(b).

The PDI measured by DLS, a technique in physics to determine the size distribution profile of small particles in suspension or polymers in solution, is used to evaluate the width of the particle size distribution (the relative variance in the particle size), and the PDI of <0.08 is typically regarded as "monodisperse."[30]

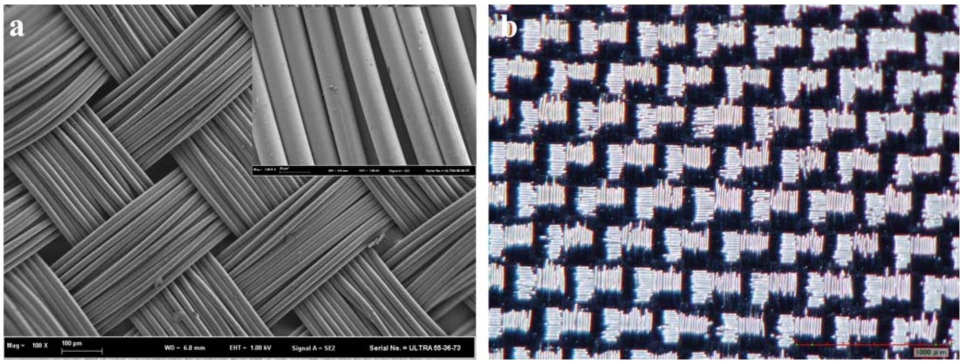

Figure 3. The morphology of polyester woven fabrics observed by (a) FESEM and (b) 3D video microscope. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

As shown in Figure 2(c), it is indicated that the peak of particle size distribution of P(St-MAA) colloidal microspheres is narrow and sharp, and all the PDI values of P(St-MAA) colloidal microspheres measured are <0.08, which demonstrates that the prepared P(St-MAA) colloidal microspheres in our study have excellent monodispersity, and it is in favor of constructing highly ordered photonic crystal structure.

Ordered Structure of P(St-MAA) Photonic Crystals on Polyester Fabrics

Figure 3(a) shows the FESEM image of original polyester woven fabrics. It can be seen that the warp yarns and filling yarns in the polyester fabrics are arranged orderly, and the fibers in same direction are less overlapped; in addition, there are a lot of gaps at the junction of warp yarns and filling yarns, which is in the typical structure characteristics of textile fabrics. Figure 3(b) shows the surface appearance of black woven polyester fabrics under the 3D video microscope. In this figure, the black filling yarns and warp yarns and the white gaps at the junction of yarns are easily seen.

During the assembly process, as the P(St-MAA) colloidal suspension was dried slowly, the disordered colloidal structure gradually transformed to the ordered crystalline structure. Figure 4 shows FESEM micrographs of P(St-MAA) colloidal crystals on black polyester fabrics fabricated by vertical deposition. The P(St-MAA) microspheres of four different diameters, synthesized by various parameters of soap-free emulsion copolymerization, were used to construct the colloidal crystals on polyester fabrics. In all cases, it was noted that the P(St-MAA) microspheres presented close-packed arrays, and their diameters measured directly from the FESEM images were smaller than

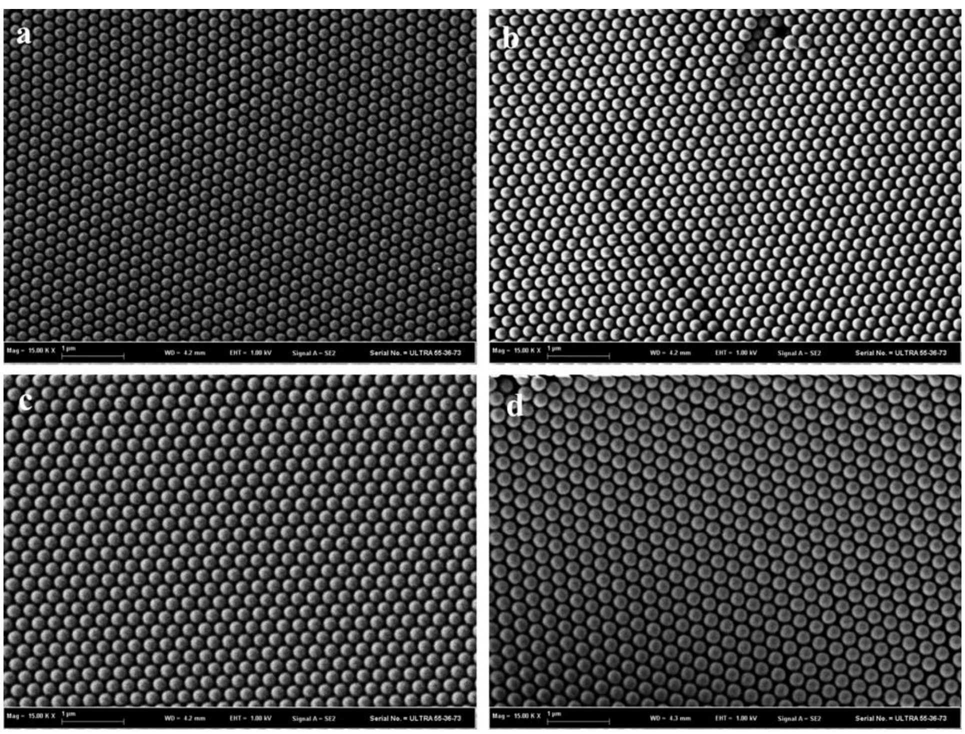

Figure 4. FESEM images of the photonic crystal structure on polyester fabrics with P(St-MAA) microspheres of different diameters: (a) 206 nm, (b) 237 nm, (c) 272 nm, and (d) 280 nm.

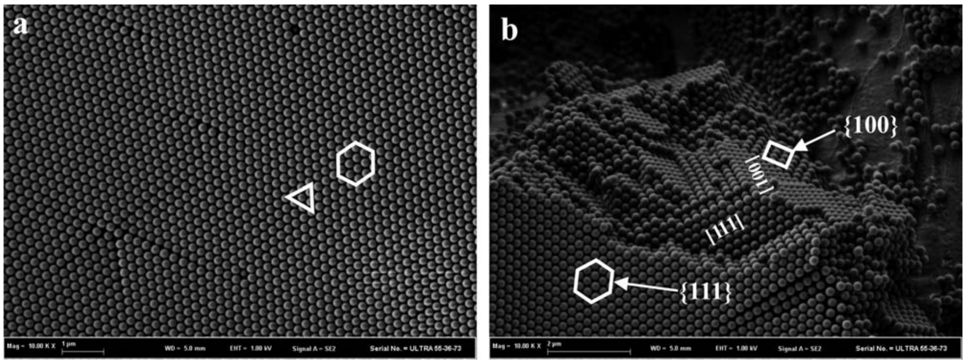

Figure 5. (a) The top view of colloidal crystals on polyester fabric (10,000×); (b) the different crystalline planes of colloidal crystals on polyester fabric (10,000×).

those determined by DLS by approximately 10–15% owing to the shrinkage of the P(St-MAA) microspheres on drying in the colloidal crystals.[24]

The top view of P(St-MAA) colloidal crystals on polyester fabric is shown in Figure 5(a). It is presented that the P(St-MAA) colloidal microspheres are packed in a close-packed arrangement, with each microsphere neighboring six others in a layer, corresponding to (111) plane of fcc or (001) plane of hcp.[30] Figure 5(b) shows the cross-section of P(St-MAA) photonic crystal structure on polyester fabrics. It is observed that colloidal microspheres are arranged closely and orderly over the entire substrate area, especially, square and hexagon arrangements, respectively, of P(St-MAA) microspheres are obviously shown. However, a rectangular alignment with one microsphere in the center and four spheres at the corners, corresponding to hcp stacking, is never found in this investigation, which meant that the resulting close-packed structure of P(St-MAA) microspheres was not compatible with the hcp packing. Actually, a square arrangement shown in Figure 5(b) corresponds to {100} type plane of fcc structure, whereas a hexagon arrangement corresponds to {111} type plane in fcc structure, which can directly confirm the 3D fcc structure of the resulting P(St-MAA) photonic crystals on polyester fabrics in our study.[31]

Full Color P(St-MAA) Photonic Crystals on Polyester Fabrics

As far as the applications of photonic crystals on solid substrates to be concerned, when the photonic band gap falls into the visible region, photonic crystals can exhibit brilliant color. In our study, it was found that the P(St-MAA) photonic crystals fabricated by vertical deposition on polyester fabrics exhibited brilliant monochromatic colors, covering the entire visible region as well. In addition, by controlling the concentrations of St, MAA, and APS in the copolymerization system, the photonic crystals with various sizes of colloidal microspheres presented different structural colors on polyester fabrics.

Figure 6(a) shows the photographs of the as-prepared structural colors on the black polyester fabric taken by a digital camera. It can be seen that the surfaces of black polyester fabrics are completely covered with P(St-MAA) photonic crystals fabricated by vertical deposition, and present bright and uniform structural colors, which arose from light diffraction/reflectance (opalescence) of the colloidal arrays, indicating long range ordering of the colloidal crystals visualized directly by FESEM as shown in Figure 5. Especially, in Figure 7, we can clearly distinguish the warp yarns and the filling yarns in colorful polyester fabrics taken by 3D microscope. In addition, Figure 6(a) shows the various structural colors of magenta, orange, yellow, green, cyan, blue, and violet generated from the photonic crystals as well, constructed by the P(St-MAA) microspheres with different diameters of 305, 280, 272, 250, 237, 206, and 190 nm, respectively, in which the violet color seems to be similar to the blue one owing to the reflection of the colloidal crystals and the sensitivity of digital camera. Therefore, it can be verified that the structural colors vary with the different microsphere sizes; that is, the structural colors of photonic crystals on polyester fabrics can be tuned by adjusting the size of the P(St-MAA) colloidal microspheres.

Figure 6(b) shows the corresponding reflectance spectra of different structural colors on polyester fabrics shown in Figure 6(a). It is noticed that when the microsphere size increases from 190 to 305 nm, the peak wavelengths of structural colors red-shift from 410, 452, 497, 529, 575, 595, to 628 nm, respectively, which could be explained by Bragg's law taking into account Snell's law of refraction[32,33]:

$$\lambda_{\max} = \frac{2d_{\mathrm{hkl}}}{m}\left(n_{\mathrm{avg}}^{2} - \sin^{2}\theta\right)^{1/2}$$

where $\lambda_{\max}$ is the wavelength of the reflectance peak maximum (i.e., the position of the photonic band gap), d_{hkl} is the interplanar spacing between hkl planes, m is the order of the Bragg diffraction, n_{avg} is the average refractive index of the photonic structure, and θ is the angle between the incident light and the surface normal of the sample (same as viewing angle).

As the microsphere size increases and other parameters in this equation remain constant, the position of the reflection peak shifts to a longer wavelength, implying that the photonic band gap positions are red-shifted as the colloidal particle size increases, otherwise, the position of the band gap could also be shifted to the blue side of the visible spectrum by reducing microsphere sizes.

In addition, to vary the particle sizes, changing the viewing angle is regarded as another simple approach to turn the structural color of photonic crystals. In Figure 8, the P(St-MAA) photonic crystals on polyester fabrics exhibit different structural colors at different viewing angles from 0 to 90° measured by a

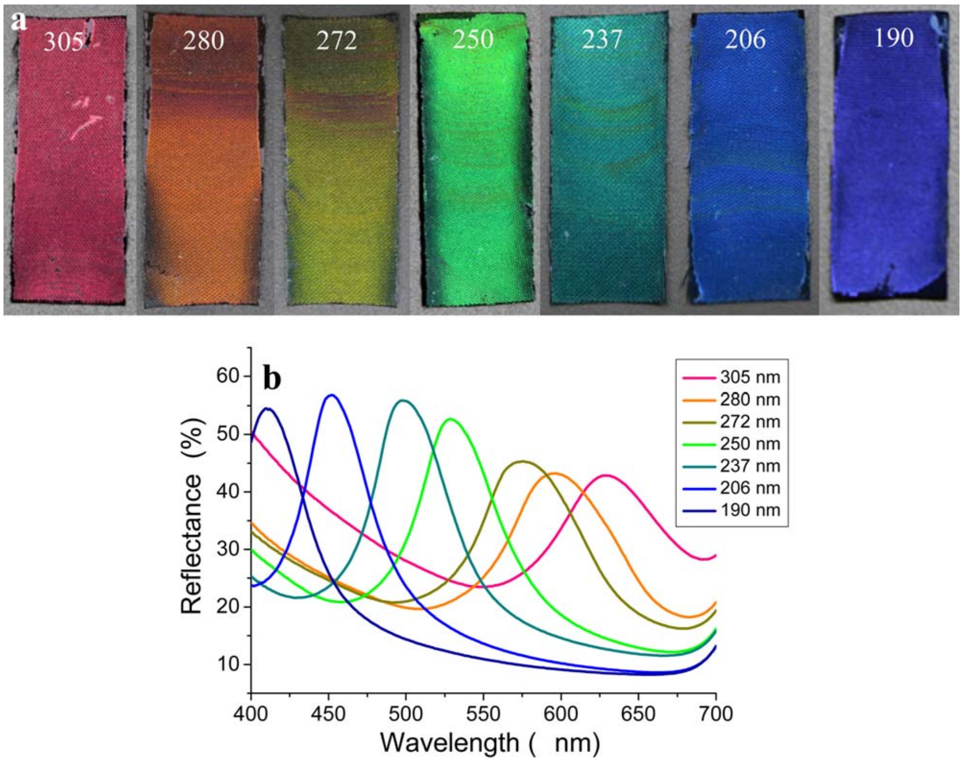

Figure 6. The structural colors (a) and reflectance spectra (b) of photonic crystal structure on polyester fabrics with the incident light normal ([111] direction) to the polyester woven fabric substrate. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

digital camera, namely, the wavelengths of structural colors move to shorter wavelength with increased viewing angles. Generally, the structural colors of photonic crystals look iridescent owing to the light scattering at different orientations of the crystallines, which is one of the significant features of the structural color and can be observed at different viewing angles.

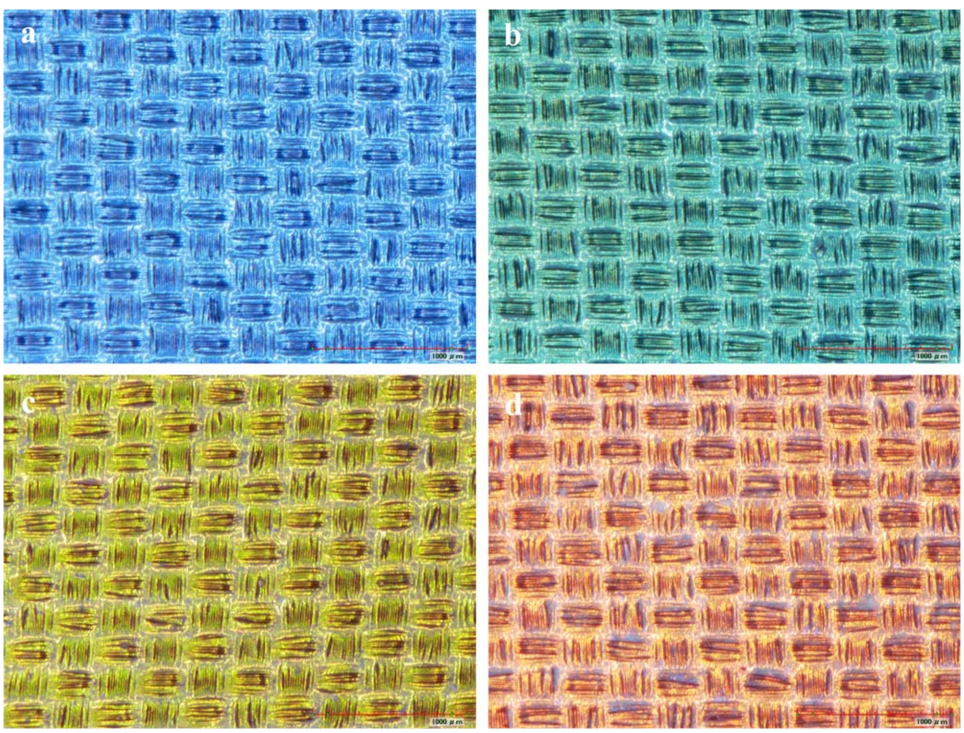

Figure 7. The morphology and structural color of polyester fabrics assembled by P(St-MAA) microspheres of different diameters (a) 206 nm, (b) 237 nm, (c) 272 nm, and (d) 280 nm corresponding to Figure 4. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

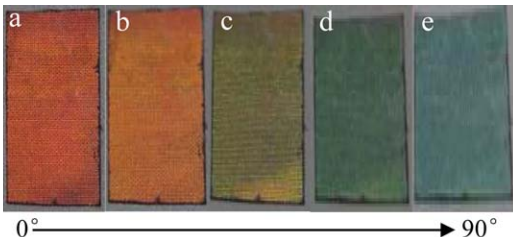

Figure 8. Photographs of various structural colors on the polyester fabrics fabricated by the colloidal microspheres with the same diameter of 280 nm at different viewing angles from 0 to 90°. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Although the iridescence phenomenon of structural color on polyester fabrics was observed by the digital camera, it was very difficult to catch all of the structural color variation, control the accurate viewing angles, and provide the reflection spectra of corresponding structural colors at different viewing angles subjected to the sensitivity and functional limitation of digital camera. In our research, a multiangle spectrophotometer was introduced to study the relationships among the exact viewing angles, structural colors, and their reflection spectra. Figure 9(a) shows a series of various structural colors on polyester fabric at different aspecular viewing angles with the incident light source at 45 and 15°. Figure 9(b,c) shows the corresponding reflectance spectra of the structural colors shown in Figure 9(a). It is observed that there are very different positions and intensities of the reflection peaks for the same photonic crystals on the polyester fabric at different viewing angles. Notably, under the same testing light source, the peak wavelength of reflectance spectra varied with the different testing angles is well in line with the structural color changes shown in Figure 9(a), implying that the photonic band gap positions of the prepared photonic crystals are shifted by changing the viewing angles. In addition, it is noticed that some reflectance intensity data shown in Figure 9(b,c) are more than 100% in certain angles higher than the conventional reflectance obtained from a UV–Vis spectrometer. However, it is normal for this kind of multiangle spectrophotometer as long as the intensities of reflectance spectra measured are in the range of 0–400% in agreement with the ASTM E2539-08 (http://www.xrite.com/documents/manuals/en/MA98-500_Multi-Angle_User_Guide_en.pdf.).[25]

CIE $L^*a^*b^*$ (CIELAB) is the most complete color space specified by the International Commission on Illumination (CIE), which describes all the colors visible to the human eye and is created to serve as a device independent model to be used as a reference.[34] The $L^*a^*b^*$ values listed in Table I show the detailed changes of the structural colors on polyester fabrics with eight diversified angles measured by the multiangle spectrophotometer. The $L^*a^*b^*$ space consists of a luminosity "L^*" layer, chromaticity layer "a^*" indicating where color falls along the red–green axis, and chromaticity layer "b*" indicating where the color falls along the blue–yellow axis. The quantity of color could be evaluated by the chromaticity $(a^{*2} + b^{*2})^{1/2}$.[35] The $L^*a^*b^*$ values listed in Table I indicate that the same polyester fabric samples show various lightness and chromaticity at different aspecular viewing angles with the incident light source at 45and 15°, and the highest brightness colors could be indicated at the angle of "45 as −15" and "45 as 15", which are in agreement with the photograph and reflectance spectra shown in Figure 9.

Comparison of Self-Assembly Effect Between Vertical Deposition and Gravitational Sedimentation

In our previous study, a gravitational sedimentation self-assembly method was applied for fabricating PSt photonic crystal structure on polyester fabrics.[22] Compared to gravitational sedimentation, the vertical deposition is a more simple and effective self-assembly method to fabricate 3D colloidal crystals

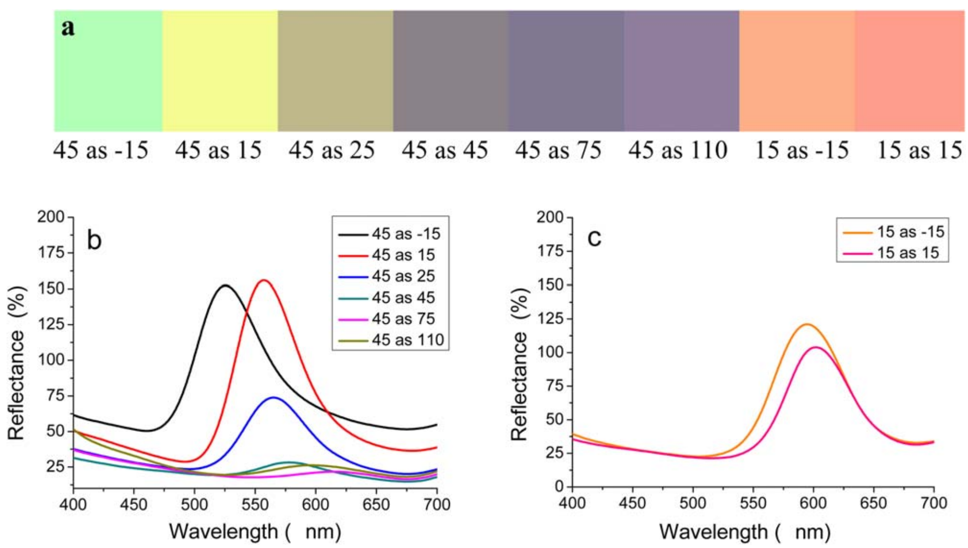

Figure 9. Photograph and reflectance spectra of structural color on polyester fabrics characterized by multiangle spectrophotometer: (a) the structural color photograph at different viewing angles; (b) the reflectance spectra of the testing light source at 45°; (c) the reflectance spectra of the testing light source at 15°. It should be noted that the colloidal microspheres with the same diameter of 280 nm; the angle "45 as −15" means the sample was directionally illuminated at 45° from the normal, and the aspecular viewing angles in plane were at −15°; others can follow by analogy. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table I. The CIELAB Values Under 10°/D65 Standard Conditions of P (St-MAA) Photonic Crystals Assembled by the Colloidal Microspheres with the Diameter of 280 nm at Different Testing Angles

Angle	*L**	*a**	*b**
45 as −15	100.22	−43.99	35.09
45 as 15	96.45	−13.84	49.69
45 as 25	74.02	−2.76	23.64
45 as 45	55.03	4.19	−2.37
45 as 75	51.64	7.77	−13.63
45 as 110	55.02	12.05	−12.06
15 as −15	81.25	34.71	36.37
15 as 15	79.55	48.88	32.00

Note: The angle "45 as −15" means the sample was directionally illuminated at 45° from the normal and the aspecular viewing angles in plane were at −15°.

on textile fabrics. In addition, the resultant polyester fabrics achieved by vertical deposition self-assembly method exhibit some interesting characteristics as summarized in Table II. It is clear that both gravitational sedimentation self-assembly and vertical deposition self-assembly can confer vivid and variable structural colors to the fabrics but there are some distinguished differences between the gravitational sedimentation and the vertical deposition on the polyester fabrics. Gravitational sedimentation is believed as the easiest assembly method driven by gravity of colloidal microspheres, and actually involves a coupling of complex processes such as gravitational settling, translational diffusion (or Brownian motion), and crystallization (nucleation and growth).[9] Nevertheless, vertical deposition is driven by capillary force which can transfer the colloidal microspheres to the assembled substrate during the evaporation of microsphere emulsion; that is, the microsphere emulsion evaporation causes a convective microsphere flux from the bulk of the colloidal suspension toward the drying microsphere layer. The balance between capillary force and convective microsphere flux during the evaporation process is essential for the formation of 3D colloidal crystals.[36,37] Owing to the different mechanisms and processes of those two assembly methods, it is inevitably to generate different coloration effects on polyester fabrics. The vertical deposition is able to achieve double-sided

Table II. The Comparison of Gravitational Sedimentation and Vertical Deposition on Polyester Fabric

Content	Gravitational sedimentation	Vertical deposition
Structural color	Vivid and monochromatic	Vivid and monochromatic
Main driving force	Gravity	Capillary force
Coloration effect	Single sided	Double sided
Thickness of the photonic crystals	Thick	Thin
Clarity of the texture	General	Obvious

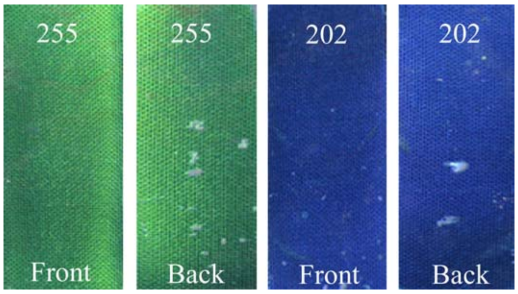

Figure 10. The double-sided coloration of photonic crystal structure on polyester fabrics with the incident light normal ([111] direction) to the polyester woven fabric substrate. The photonic crystals with P(St-MAA) microspheres of different diameters: (a) and (b) 255 nm; (c) and (d) 202 nm. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

coloration effect on polyester fabrics owing to its particular assembly mode as shown in Figure 1, which is different from the single-sided coloration effect of the gravitational sedimentation. As shown in Figure 10, it is found that both the front and the back sides of polyester fabrics present identical structural colors, which is so similar to the color effect achieved by traditional immersion dyeing method using dye bath. It is also noticed that the warp yarns and filling yarns on the colored polyester fabrics by vertical deposition can be clearly observed by visual observation, but it cannot be seen from the sample by gravitational sedimentation. Hence, it is supposed that the thickness of the photonic crystal structure fabricated by the vertical deposition on polyester fabric is much thinner than that by the gravitational sedimentation, which is favorable to keeping a soft fabric handle.

CONCLUSIONS

In this article, vertical deposition self-assembly was applied to fabricate the photonic crystals of fcc arrangement on textile products and endowed the polyester fabrics with uniform and brilliant structural colors owing to Bragg diffraction of the well-ordered photonic crystal structure without any chemical dyes and pigments. The structural colors of photonic crystals on polyester fabrics were governed by the photonic band gaps dependent on the different viewing angles and spherical sizes of P(St-MAA) microspheres, and the resultant polyester fabrics presented various color effects. More importantly, the structural colored fabric through the vertical deposition method presented some favorable properties including double-sided coloration effect, clear fabric texture, and soft fabric handle. The structural coloration by vertical deposition self-assembly of P(St-MAA) photonic crystals may provide a new strategy for textile coloration without using chemical colorants and has a potential ability to reduce the pollution in the current textile dyeing and printing processes.

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