Journal of Ceramic Processing Research. Vol. 19, No. 6, pp. 479~482 (2018)

J O U R N A L O F
Ceramic Processing Research

Effect of nano-carbon addition on color performance of polystyrene superstructure film

Ye-min ZHOU, Li-li Wang[a], Xiao-peng LI, Xiu-feng Wang and Hong-tao Jiang
Key Laboratory of Auxiliary Chemistry & Technology for Chemical Industry, Ministry of Education, Shaanxi University of Science & Technology, Xi'an, Shaanxi 710021, China

Polystyrene superstructure films show faint rainbow color, and this low color saturation limits its wide application. In this paper, polystyrene superstructure films with single bright blue color were prepared by vertical deposition self-assembly method using polystyrene microspheres with average diameter of 310 ± 10 nm as raw material. Polystyrene superstructure films were modified by adding nano-carbon powder, and effect of the amount of nano-carbon powde on color performance was studied. The results showed that without addition of nano-carbon powder, the superstructure films showed a faint rainbow color, while with addition of nano-carbon power, the superstructure films exhibited a single bright blue under the same natural light source. Changing the amount of nano-carbon powder addition could adjust color saturation of the film. With increasing the amount of nano-carbon powder addition from 0.008 wt% to 0.01 wt%, color saturation of the superstructure film increased gradually. Further increasing the amount of nano-carbon powder addition to 0.011wt%, color saturation of the superstructure film didn't increase anymore and tended to get dark.

Key words: Polystyrene, Structure color, Carbon addition, Modified.

Introduction

Dyes and pigments can produce the colors because they selectively absorb and reflect certain wavelengths of visible light [1-3]. Natural photonic crystals are responsible for strong reflectance at selective wavelengths in different natural systems [4-5]. The most striking property of such crystals is the appearance of wavelength ranges in which the propagation of light is forbidden, the so called photonic stop-bands [6-7]. If the photonic band gap falls into the visible light range between 380 nm and 780 nm, visible light of specific wavelengths is not allowed to propagate in the photonic crystal structure, thus being selectively reflected [8-9]. Among all kinds of techniques for preparing, self-assembly of monodisperse colloidal spheres has attracted wide attention due to its simple fabrication. The self-assembly method, in particular colloidal crystals, a sonication-induced assembly of monodisperse colloidal particles which can be performed under ambient pressure and temperature is most often reported because of its lower processing cost, higher production efficiency, and ease of use in the visible region [10-13].

Different from chemical colors, structural colors depend on physical structure instead of selective light absorbing, thereby protecting materials from photobleaching [14-15]. Then the structural colors with high brightness, high saturation, less discoloration and iridescent effect would be produced on the surface of periodic photonic crystals. The creatures displaying brilliant structural colors are prevalent in nature, and their life, including communication, shielding, and other biological functions, is closely linked with these structural colors [16-17].

Structural colors are attracting considerable attention for their advantages of environmental friendliness and resistance to fading. However, currently, low color saturation and intrinsic iridescent color restrict their widespread application.

In this paper, polystyrene (PS) superstructure films were fabricated by vertical deposition self-assembly method and nano-carbon powder was added in order to increase the saturation of PS superstructure films. Effect of various amount of nano-carbon powder addition on morphology and color performance of PS superstructure films was investigated. The mechanism of nano-carbon powder addition on color performance of the as-prepared PS films was explored.

Experimental Procedures

Uniform monodisperse PS microspheres with average size of 310 ± 10 nm were prepared by emulsion polymerization method using styrene as monomer under nitrogen atmosphere. The as-prepared emulsion was then diluted to 0.1 wt%, divided into two equal parts and put them into weighing bottles, respectively. A certain amount of nano-carbon powder was added into

*Corresponding author:
Tel : +18391009638
Fax: +029-86168688
E-mail: mariawanglili@126.com

one of the weighing bottles, and the mixed emulsion was dispersed by ultrasound for 30 minutes. Then a glass slide was vertically inserted in it, placing in natural environment for 2 days. Uniform and smooth PS superstructure films were prepared by this vertical self-assembly method. Effect of nano-carbon addition on the morphology and color saturation of PS superstructure film was compared with that of the films without nano-carbon addition.

The diluted PS emulsion with 0.1 wt% concentration was divided into four equal parts, putting into four weighing bottles and 0.008 wt%, 0.009 wt%, 0.010 wt% and 0.011 wt% nano-carbon powder were added in them, respectively. Ultrasonic dispersion for 30 minutes was carried out and a glass slide was vertically inserted and fixed in each one. Nature dried for two days. Effect of various amount of nano-carbon powder on the morphology, color saturation and angle dependence of the film were compared with each other.

The morphology of as-prepared PS superstructure films was characterized by SEM. The distribution and dispersion of the added nano-carbon particles in the PS crystal lattice were observed. The color performance of PS superstructure films was characterized by digital camera. The reflectance intensity and position of the reflection peak in the UV-Vis spectrogram of the as-prepared PS films were determined.

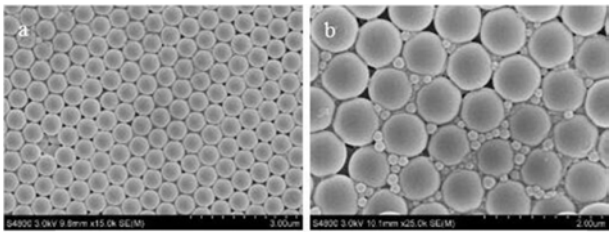

Fig. 1. SEM images of polystyrene superstructure films (a) without nano-carbon addition; (b) with nano-carbon addition.

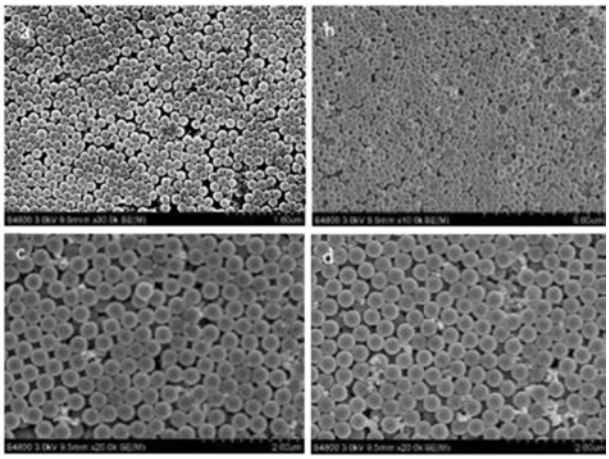

Fig. 2. SEM images of PS superstructure films with various amount of nano-carbon powder addition (a) 0.008 wt%; (b) 0.009 wt%; (c) 0.010 wt%; (d) 0.011 wt%.

Results and Discussion

Morphology of polystyrene superstructure film

Fig. 1 shows SEM images of PS superstructure film prepared by vertical deposition self-assembly method in Φ35 cm weighing bottle dried at 60 ºC with and without nano-carbon addition. It can be seen from Fig. 1(a) that when the concentration of PS emulsion was 0.1 wt% and the drying temperature was 60 ºC, PS microspheres were arranged in an orderly and regular structure with dense hexagonal arrangement. As shown in Fig. 1(b), PS superstructure film was prepared by adding a certain amount of nano-carbon powder into the same PS emulsion. Nano-carbon particles were distributed among the gap of PS hexagonal arrangement. Since the agglomeration of nano-carbon powder, PS microspheres were relative loosely arranged compared with that without nano-carbon powder addition, and the whole structure was still arranged as ordered and dense hexagonal stacking. At the same time, since filling of nano-carbon particle, pores among PS superstructure were reduced.

Fig. 2 indicates SEM images of PS superstructure films prepared by adding various amount of nano-carbon powder. It can be observed in Fig. 2(a) that when the addition of nano-carbon was about 0.008 wt, the arrangement of PS microspheres was regular with only a few defects. As shown in Fig. 2(b), when nano-carbon addition was increased to 0.009 wt%, small amount of PS microspheres left the original lattice position, leading to an increase in defects. Fig. 2(c) shows the vacancy formed by the loose arrangement of PS microspheres was increased, with the addition amount of nano-carbon continuing to increase. In Fig. 2(d), with further increasing the amount of nano-carbon powder to 0.011 wt%, more PS microspheres jumped away from the original lattice position and more cracks in the arrangement of PS microspheres and more agglomerations of nano-carbon powder were observed.

Effect of nano-carbon addition on color performance of polystyrene superstructure film

Fig. 3 reveals the comparative photographs and UV-Vis spectra of PS superstructure films with various amount of nano-carbon powder addition. Low color saturation and light blue-green of PS superstructure films were observed in Fig. 3(a), when nano-carbon addition was 0.008 wt%. Fig. 4(b) demonstrated relative high color saturation and single bright blue of PS superstructure film were observed, when nano-carbon addition was increased to 0.009 wt%. Fig. 4(c) displays when nano-carbon addition increased to 0.010 wt%, color saturation of the film decreased slightly, and small parts of the films showed bright green. Color saturation of PS superstructure film decreased and even became dark with further increasing the amount of nano-carbon powder to 0.011 wt%, as shown in Fig. 4(d).

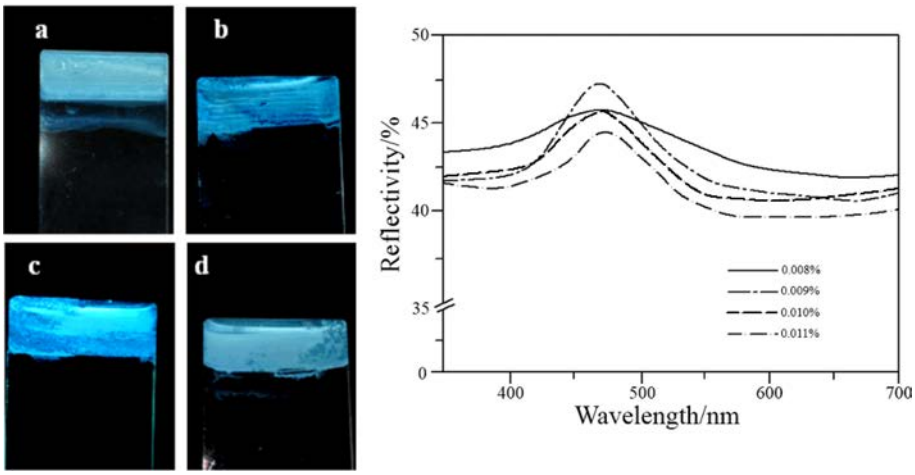

Fig. 3. Color photographs and UV-Vis Spectra of PS superstructure films with various amount of nano-carbon addition (a) 008 wt%; (b) 0.009 wt%; (c) 0.010 wt%; (d) 0.011 wt%.

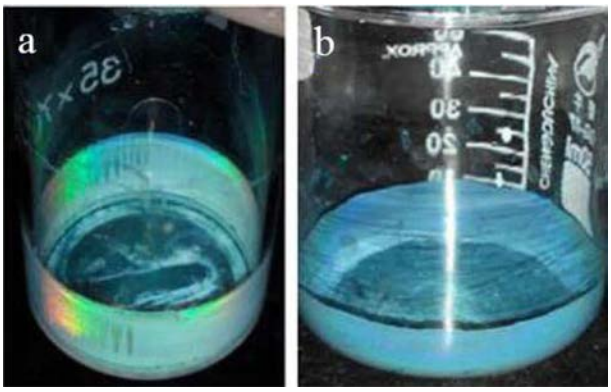

Fig. 4. Color performance of PS superstructure films (a) without nano-carbon addition; (b) with nano-carbon addition.

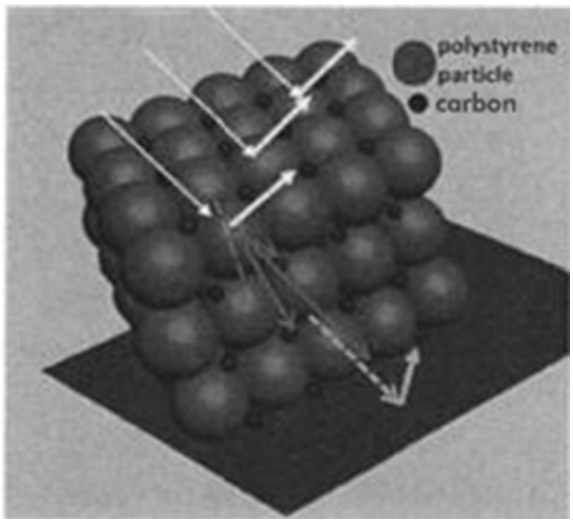

Fig. 5. Schematic of mechanism of color performance of PS superstructure film.

The Ultraviolet-Visible spectra of PS superstructure films with various amount of nano-carbon addition shows a single photonic band gap peak within the blue wavelength range. With increasing the amount of nano-carbon addition, nano-carbon particles in the superstructure films absorbed more stray light, which led to the decrease of the reflectance intensity, while the reflection peaked in the blue wavelength range became more prominent. When the amount of nano-carbon powder addition exceeded 0.01 wt%, more parts of blue lights were absorbed, which resulted in the decrease of reflection intensity of blue light by PS superstructure film.

Fig. 4 indicates color photographs of PS superstructure films with and without nano-carbon addition under natural light. It can be observed in Fig. 4(a) that part of PS superstructure film without nano-carbon addition showed bright iridescence, while, with nano-carbon addition, PS superstructure film exhibited single blue under the same natural light source. Meanwhile, it was also found that when the angle of incident light changed, PS superstructure film without nano-carbon addition showed different colors, while bright single blue color was observed on the PS superstructure film with nano-carbon addition, which suggested addition of nano-carbon can improve the angle dependence of PS superstructure film.

Mechanism of color performance of polystyrene superstructure film

As shown in Fig. 5, when a beam of natural light shined on the surface of PS superstructure film with nano-carbon addition, band gap light was completely blocked by the three-dimensional structure, and reflected at the interface. Other wavelengths of light entered into the three-dimensional structure through defects in gaps. Some of the light inside the structure was completely absorbed by nano-carbon powder in the gap, and the other part was also completely absorbed by nano-carbon powder when reflected on the substrate through the structure. However, because of the complete reflection at the interface, effect of nano-carbon powder was relatively small, leading to the increase of the purity and relative intensity of forbidden light. When the light came into PS superstructure

without nano-carbon addition, after diffraction and reflection, the reflected light on the interface mixed with forbidden band light, which affected the color of the forbidden light, resulting in reducing of the relative intensity of forbidden band light. Color of the original PS superstructure which was influenced by the band gap and mixing stray light became weak, white, and low brightness. Therefore, proper amount of nano-carbon powder addition can significantly improve color saturation of PS superstructure film.

Conclusions

PS superstructure films with high saturation single bright blue color were successfully prepared by vertical deposition self-assembly method in Φ35 cm weighing bottle dried at 60 ºC with nano-carbon powder addition. Nano-carbon powder addition had a significant effect on color performance of PS superstructure films. Since nano-carbon absorbed the stray light of other wavelengths, PS superstructure film with nano-carbon powder addition showed a single bright blue under natural light. With increasing the amount of nano-carbon powder addition from 0.008 wt% to 0.01 wt%, color saturation of the film increased gradually. Further increasing the amount of nano-carbon powder addition to 0.011 wt%, color saturation of the film became weak and changed to dark, which suggested nano-carbon powder addition could improve color saturation of the film and changing the amount of nano-carbon addition could adjust color saturation of the film. This is a unique way to obtain single color with high color saturation, which will expand the application field of PS superstructure films.

Acknowledgements

This work was supported by National Foundation of Natural Science, China (51402179, 51272149), Dr. Scientific Research Foundation of Shaanxi University of Science & Technology (BJ14-17).

References

1. L.G. Martin, M. Nathan, and L. Joseph, Sci.Adv. 4[4] (2018)8909-8917.
2. A. Yadav, R.D. Angelis, and M. Casalboni, Opt.Mater. 35[8] (2013) 1538-1543.
3. Z. Lan, L. Yichen, and L. Guojin, Dyes Pigments. 133[5] (2016) 435-444.
4. L. Yichen, Z. Lan, and Z. Guoqing, Surf. Coat. Tech. 319[8] (2017) 267-276.
5. L. Fan, P.J. David, and S. Andreas, Chem.Int.Edit. 50[2] (2011) 360-388.
6. H.I.Lara, A.M. Neal and T.E. Mallouk, J. Phys. Chem.B.109[13] (2005) 6334-6342.
7. B.V.Paul, R.W.Zehner, and W.A. Christopher, Adv.Mater. 13[10] (2001) 721-724.
8. Z. Huilin, G. Jianping, and P. Zeng, J. Phys. Chem.C 120[22] (2016) 11938-11946.
9. F.Georg, K.Vladimir, and L.V. Bettina, Chem. Soc. Rev. 42[7] (2013) 2528-2554.
10. G.Dengteng,Y.Lili,and W. Gaoxiang, Chem. Commun. 50[19] (2014) 2469-2472.
11. L. Cheho, K. Hyelim and K. Shinhyun, Langmuir 30[28] (2014) 8350-8356.
12. L. Feihu, T. Bingtao, and W. Suli, Small. 13[3] (2017)1-8.
13. L.Guojin, Z. Lan, and Z. Guoqing, Mater.Design 114[12] (2017) 10-17.
14. L. Fangfang, S. Bin, and Z. Shufen, Langmuir 34[13] (2018) 3918-3924.
15. D. Guohua, T. Chuanmei, and L. Fuya, Macromolecules. 43[3] (2010) 1191-1194.
16. C. Yao, Z. Fuyin, and L. Jie, Adv. Mater. 26[30] (2014) 5184-5190.
17. L. Chenghui, W. Chao, and K. Christoph, Nat. Chem. 8[6] (2016) 618-624.