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Monodisperse Silica Nanoparticle–Carbon Black Composite Microspheres as Photonic Pigments

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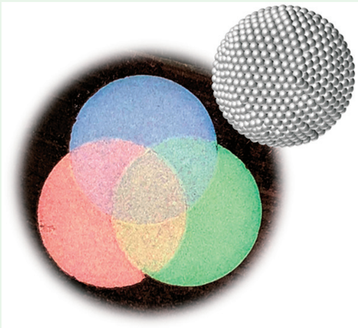

ABSTRACT: The development of nonbleachable colorants made of safe and inexpensive materials is a scientifically important task in view of future environmental and biological impacts. In this study, the conditions under which spherical colloidal crystals (photonic balls) formed mainly of sub-micron-sized monodispersed silica fine particles and carbon black exhibit vivid structural coloring were systematically investigated. The (111) plane of the face-centered cubic colloidal crystal formed by the silica particles is mainly oriented on the surface of the photonic balls formed from monodispersed silica particles. As a result, light in a specific wavelength region is reflected from the photonic balls according to the Bragg condition. When silica particles with diameters of 221, 249, and 291 nm are used, the peaks of the Bragg reflections generated from the photonic balls occur at 495, 562, and 647 nm, respectively; each photonic ball exhibits the ability to produce blue, green, and red colors. In particular, when a black background is used, a vivid structural color is observed from each photonic ball, and it is possible to reproduce all colors using the three primary colors of light by changing the mixture ratio of these photonic balls. The introduction of a small amount of carbon black into the photonic balls makes it possible to reproduce the additive color mixture by the three primary colors of light even when the background color is white. We report that safe and nonbleachable coloring materials with controlled nanosized periodic structures and micrometer-sized geometric structures can be developed using three types of photonic balls consisting of safe and inexpensive silica fine particles with/without carbon black.

KEYWORDS: *photonic ball, photonic pigment, structural color, silica particle, carbon black*

■ INTRODUCTION

Structural colors are used by all living organisms, such as birds, fish, insects, mammals, reptiles, and plants and are also found in minerals.[1] We humans also use gemstones and shells that exhibit structural colors as jewelry, but we rarely use structural coloring materials as pigments. Materials displaying structural colors can be prepared from only safe raw materials and can be nonfading,[2] so they will be useful coloring materials in the future. Such a structural colored material could be used not only as a substitute for conventional coloring materials but also for new solar cells and optical devices that are expected to be developed in the future,[3,4] and research on new structural colored materials utilizing nanotechnology is being actively conducted.

Conventionally, it has been considered that materials exhibiting structural colors have different refractive indexes and have a periodic ordered structure at the wavelength of visible light. As a result, visible light of a specific wavelength mainly reflected by the Bragg condition interferes, a shining color with a high reflectance is obtained, and the hue of the color changes largely depending on the angle. We reported that a short-range ordered structure can change the refractive index, causing light of a specific wavelength to scatter and interfere. This results in a structural color and a hue with less angular dependence.[5−8] In addition, we found that black material was needed to improve the saturation of the structural color resulting from this short-range ordered structure.[9−11] Based on these results, we worked to make color materials with little angle dependence using only white and black materials made of safe substances that can be used in cosmetics and foods.[2] According to the conventional idea of a color material, when a white material and a black material are mixed, the color becomes gray, and a chromatic color is never obtained. On the other hand, using a white material to construct a fine ordered structure that selectively scatters light of a specific wavelength in all directions and suppresses the scattering of light in other wavelength regions with a black material results in a material that displays a structural color with low angle dependence. However, the structural color generated from a system with a

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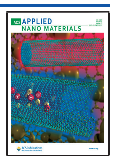

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