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Short note

Dynamic structural color in the nacre of *Hyriopsis Cumingii* and its cause

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ABSTRACT

The structural color and microstructure of the nacre of *Hyriopsis Cumingii* were investigated by using reflection spectra, theoretical simulation, and scanning electron microscopy, respectively. The results indicate that the structural color of the nacre of *Hyriopsis Cumingii* can obviously red-shift from blue to red along the growth pattern direction from posterior to anterior of the nacre. The observed, measured, and theoretical simulated results of the structural color are rather consistent, revealing that the structural color of the nacre in the bivalve shell of *Hyriopsis Cumingii* is derived from the one-dimensional photonic structure which is composed of period oriented alternatively aligned aragonite platelets and protein layers. The lattice period of the one-dimensional photonic structure increased significantly along the growth pattern direction from posterior to anterior of the nacre, which leads to red-shift of the structural color obviously.

1. Introduction

Biological photonic crystals are composed of two materials with different refractive indices as a periodic structure, have received considerable attention due to their potential application in the fields of biomimetic materials and sensing devices [1,2]. When the wavelength of the incident light falls into the photonic bandgap, it will be fully reflected and appear corresponding structural color. At present, a variety of bio-photonic structures have been reported in the nature, such as two-dimensional photonic structures in the hairs of blind golden moles [3,4], butterfly wings [5,6], bird feathers [7,8], and bivalve ligaments [9–11], three-dimensional photonic structure in weevil [12]. Through systematic research for the bio-photonic structures in the nature, can provide new ideas and templates for biomimetic synthesis high performance photonic devices.

Bivalve nacre has received considerable attention in the fields of physics, materials science, and biology, due to their bright iridescent color which belonging to structural color. At present, more recognized views for the cause of the iridescent color in bivalve nacre including thin film interference [13], grating diffraction [14,15], the combined effect of these two effects [16,17], and one-dimensional photonic band gap structure [18]. From our knowledge, at present, most of the relevant research literature for the structural color in the nacre are about seawater shells, and believe that the aragonite platelets of the nacre in different parts are uniform, so the nacre can exist uniform structural color in different parts, which is contradicted with our observed results in the nacre of *Hyriopsis Cumingii*.

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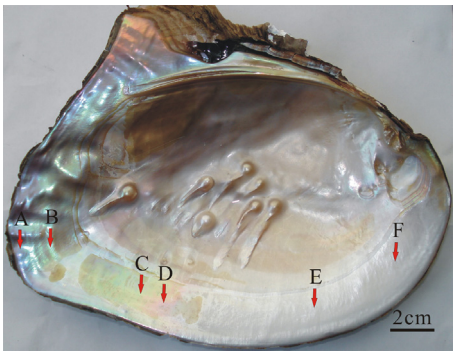

Fig. 1. Optical photo of the nacre of *Hyriopsis Cumingii* (A, B, C, D, E, and F showing blue, green, yellow green, red, white, and white area, respectively). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In this paper, the microstructure and structural color in different parts of the nacre of *Hyriopsis Cumingii* were systematically investigated by using scanning electron microscopy, reflection spectra, and theoretical simulation, respectively. We first discovered that the lattice period of the one dimensional photonic structure in the nacre increased significantly along the growth pattern direction from posterior to anterior of the nacre, which leads to the red-shift of the structural color obviously.

2. Experimental

2.1. Materials

Samples of *Hyriopsis Cumingii* were obtained from Zhejiang Zhuji in east China. After removing the soft body, the shells were washed with distilled water and dried at room temperature for 5 days, and kept for further characterization.

2.2. Characterization

The optical photo of the nacre of *Hyriopsis Cumingii* was taken using Nikon digital camera (COOLPIXL22). The reflection spectra of the nacre were measured by using an AvaSpec-2048 fiber optical spectrometer with analyzing software of Avasoft 7.1. A halogen-tungsten lamp and a reflection probe were used as light source and probe, respectively. The incident light and the test surface were perpendicular, the distance between the probe and the test surface was about 1 mm, and the probe surface area was about 1 mm^2. A white board was used as a reference for the reflectivity. The microstructure of the nacre was observed by using an S-3400N scanning electron microscope (SEM) operated at 30 kV accelerating voltage.

3. Results and discussion

3.1. Color observation

Fig. 1 shows the optical photo of the nacre of *Hyriopsis Cumingii*. We can see bright iridescent color from the nacre on the back of the shell (left side of the photo), and the color gradually turns from blue to green and then red from left to right along the growth pattern direction, which conforms that there is a clear phenomenon of red-shift for the structural color from the nacre of *Hyriopsis Cumingii*. But the bright iridescent color can not be seen from the front of the shell (right side of the photo), which can only show the white background color.

3.2. Structural characterization

Fig. 2 shows the SEM images of the natural cross section of the nacre of *Hyriopsis Cumingii*. It can be seen that the nacre is periodic stacked by aragonite platelets and protein layers with different refractive indices, revealing that the nacre has one-dimensional photonic structural characteristics. The thickness of aragonite platelet in the same growth area is almost the same, but the thickness of aragonite platelet varies greatly in different areas, leading to the lattice period (the summation of the thicknesses of single aragonite platelet and single protein layer) significantly increased from posterior to anterior of the nacre along the growth pattern direction. The average lattice periods of the nacre are 342 ± 50 nm, 436 ± 50 nm, and 1300 ± 95 nm in the B, D, and F areas, respectively. The average thicknesses of the aragonite platelets in the B, D, and F areas are 312 ± 40 nm, 406 ± 40 nm, and 1270 ± 90 nm, respectively, and the average thicknesses of protein layers are 30 nm in different areas of the nacre.