Molecular Robots Use the Change of Colors as a Power Source: Development of an Educational Tool for Young Students by Utilizing the Structural Color Materials

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ABSTRACT

In this project, we progress the development of the molecular robots by using the volume expansion and/or contraction with the change of color and the educational tool for young students by utilizing the structural color materials. Accordingly, this article constitute of the two independent themes related with the structural color. At first, we found the first evidence for the bidirectional photo-mobility revealed by the use of difference of chemical properties in the diamine derivatives. Secondary, we improve the fabrication method of HPC solution, which can maintain the structural color for three months.

1. INTRODUCTION

Structural colors are responsible for many of the brilliant colors we see in nature. The blue of the sky, the rainbow of colors in an oil slick, the bright colors of peacock feathers, the brilliant blue of a Blue Morpho butterfly, the metallic colors of certain beetles, and the glimmering colors of some fish, are all due to structural color. In this project, we progress the development of (I) molecular robots and (II) the educational tool by using the structural color. Accordingly, this article constitute of the two independent themes related with the structural color.

I. Molecular Robots Use the Change of Colors as a Power Source

1 Introduction

The study on the photomechanical effects taken in polymer containing photochromic moieties is currently in progress, in which the incident light energy (photons) is converted into the mechanical work by photoisomerization of azobenzen and diarylethene group. In the pioneering works of Ikeda et al, the irradiation of the linearly polarized ultraviolet (UV) light on these materials results in large magnitude, unidirectional bending of cantilevers. Recently, it was revealed that the photochromic poly(L-glutamate) with the spiropyran (SP) units in the side chain (PSPLG) exhibits the helix-coil transition. This transition is triggered by the photochromism from terminal SP units to merocyanine (MC) units, as shown in Figure 1 [1]. In general, the poly(L-glutamate) was found to attend with the volume change relevant to the helix-coil transition, which is the first order transition. In other word, PSPLG can be a candidate of the photomechanical materials. In this study, we report the bidirectional photo-mobility of PSPLG gel films cross-linked with the diamine derivatives having the different chemical properties.

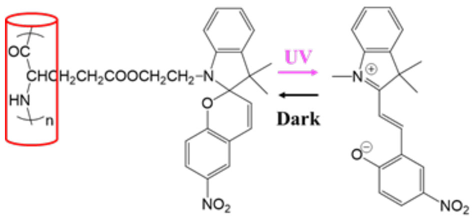


Figure 1. Photochromic behaviors of PSPLG.

2. Experimental

PSPLG was synthesized by dehydration-condensation reaction of poly(L-glutamic acid) and N-hydroxyethyl-SP by using DCC/HOBt method. The typical SP substitution ratio was estimated to be ca. 90 mol% from molar extinction coefficient at 355 nm in the observed absorption spectra. Liquid crystalline gel film was prepared by cross-linking 25 wt% solution of PSPLG in dimethylacetamide, where reveal the cholesteric lyotorpic liquid crystal. Here, we use the pentaethylenehexamine (PEHA) and 1,11-Diamino-3,6,9-trioxaundecane (DATD) as diamine derivatives (cross-linker). UV irradiation to the gel films were carried out using an 8 W handy type UV lamp (wavelength 365 nm). Photomechanical motions were record with a digital microscope.

3. Results and Discussion

Figure 2 (a) and (b) show the photomechanical responses of PSPLG gel films containing the 8 mol% PEHA and DATD to the irradiation of UV light (2 mW/cm^2) at 365 nm, respectively. Upon irradiation, PEHA gel bent forward in the direction of irradiation of light, while DATD

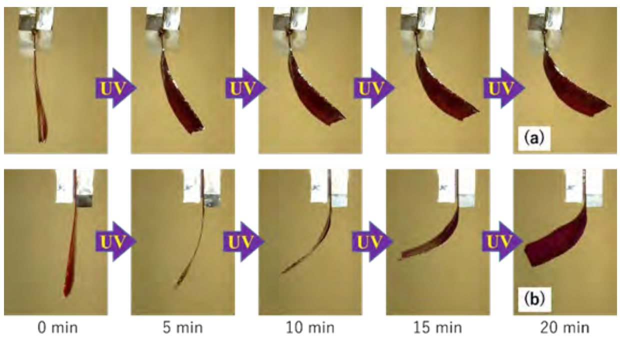


Figure 2 Variation of shape in PSPLG gel linked with 8 mol%-(a) PEHA and (b) DATD as a function of irradiation time of UV light.

gel bents toward the light. This result indicate that the volume of surface irradiating light was expanded in PEHA gel whereas it was contracted in DATD gel. To the best of our knowledge, this is the first evidence for the bidirectional photo-mobility revealed by the use of difference of chemical properties in the diamine derivatives. The mobility could be considered to be attributed to the aggregate resulted from the dipole-dipole interaction between the merocyanes with zwitterionic character, which is compound produced by the photoisomerization of SP unit.

Figure 3 shows the variation of the displacement angle (θ) as a function of the exposure time of UV light (365 nm). PEHA gels exhibit the different photo-bending behaviors due to the concentration of cross-linker while the DATD gels were identical behavior independent of the concentration of cross-linker. Interestingly, DATD gels exhibit the two-step photo-bending behaviors having an inflection point at 7 minutes. These results suggested that chemical properties and the concentration of cross-linker strongly correlated with the mechanism of the photo-bending behaviors for PSPLG gel.

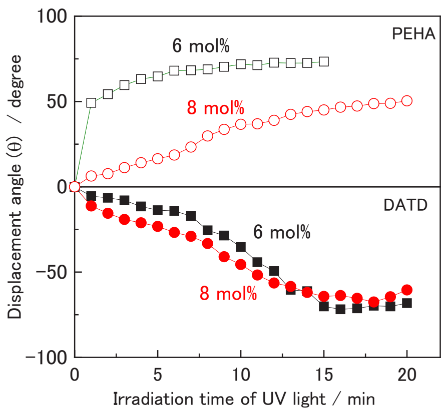
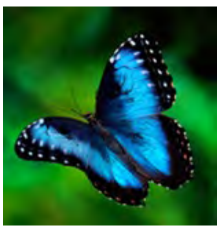


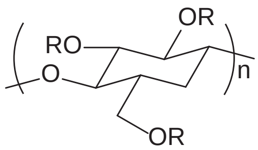
Figure 3 Variation of the displacement angle θ of (a) PEHA and (b) DATD gel actuators as a function of 365 nm light exposure time.

II Development of an Educational Tool for Young Students by Utilizing the Structural Color Materials

1. Introduction



Structural color is color that results from the way light interacts with nano- or micro-scale structures in a material. It is not due to dyes or pigments. Interference colors are an example of structural color. These colors are produced when two or more light waves interact. The interference between the waves cancels some of the colors that make up white light, but not others. The result is that a normally colorless material, like soap solution, can appear colored. Structural color could be an extremely effective probe not only in experiencing scientific interest but also on understanding the interference and diffraction of light for Japanese high school students. We focused on the hydroxypropyl cellulose (HPC) as a structural color materials (See Figure 4). HPC was found to reveal the three primary colors the by changing the concentration in the aqueous dispersion. Moreover, HPC is the medical and pharmaceutical products, being extremely safety and easy to manipulate for beginners. In this study, we report the fabrication method maintaining the structural color in the long term.



R=H or $CH_2CH(OH)CH_3$

Fig. 4 Chemical structure of HPC.

2. Experimental

HPC 5.0g (Nippon Soda Co. Ltd.) was dissolved carefully in water (2.65g) to avoid the lumps, and evacuate the vacuum storage bag with the hand pomp. After one day, the transparent HPC solution change to the brilliant red color. The detailed fabrication method will be upload as a video on YouTube.

3. Result and Discussion

Figure 5 shows the photographs of structural colors of the HCP solution. These HPC solutions can maintain the structural colors for three months, though small air bubble cannot be removed sufficiently with hand pomp.

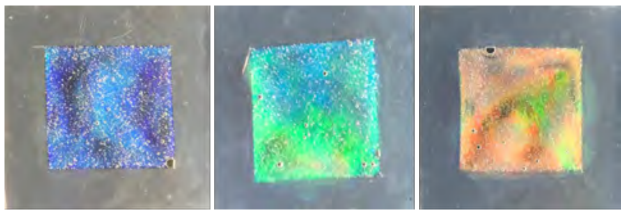


Figure 5 Photographs of Structural colors obtained from HPC solution.

As listed in Table 1, the structural colors change in order of Blue → Green → Red with decreasing the concentration of HPC solution. This result indicates to increase the cholesteric pitch in a manner of inversely proportional to the concentration.

Table 1. The concentration of HPC solution and the corresponding structural colors.

Structural Color	Water / g [a]	Concentration [b]
Blue	2.65	65.4
Green	2.90	63.3
Red	3.15	61.3

[a]: the weight of water for HPC 5g, [b]: weight percent

We will also discuss the temperature dependence of reflectance spectra for HPC solutions.

4. REFERENCES

[1] A. Fissi *et al*. *Biopolymer*, **1993**, 33, 1505-1517.