Novel Light Modulating Polymer Gel Materials Imitating Pigment Cell VI
--- Design and fabrication of a light modulator with a light modulation gel layer

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Reversible color changing materials are promising materials for various applications, such as sensors, displays, and other optical devices. We have already reported novel light modulating materials imitating the manner of the pigment cells of cephalopods utilizing volume-phase transition properties of polymer gel particles and showed that the dispersion of colored gel particles in aqueous poly(vinylalcohol) (PVA) solution exhibited excellent light modulating ability. However, it was still difficult to fabricate devices for long-time use because the aggregation among the particles occurred during the repetitive cycles of swelling and shrinking of gel particles. Here we report a new type of light modulator suitable for various applications. In this light modulator, thermo-responsive colored N-isopropylacrylamide (NIPAM) gel particles were fixed in the soft polymer matrix layer. As a result, the aggregation among the colored gel particles is prevented and the light modulator can maintain good optical property. Moreover, our light modulator is also highly flexible and applicable to mass-production.

The light modulator was prepared by the following method; Colored NIPAM gel particles, which were obtained using inverse suspension polymerization, were dispersed in water-soluble UV-curable resin and the above gel dispersion was coated on a substrate such as glass plate or plastic film etc. and cured by UV radiation and sealed. The NIPAM gel particles performed volume phase transition even in the polymer matrix of the UV resin. The solvent was hold in the polymer matrix so that leakage of the solvent from light modulation layer did not occur. The measurements of transmittance change in visible light region revealed that the light modulator using black NIPAM gel particles altered its transmittance from 20% to 80% according to temperature change. Furthermore, a durability test revealed that the light modulator maintained initial color change abilities even after 50 cycles of heating and cooling. On the other hand, a light modulator containing the same colored NIPAM gel particles dispersed in viscous PVA aqueous solution did not show such durability against the repetitive cycles due to the aggregation among NIPAM gel particles (Fig. 1). In addition, we also fabricated the flexible film type light modulator using plastic film as substrates. Fig. 2 shows flexibility and color change property of the light modulator. It is also noted that our light modulator was highly transparent especially at the colored state.

Reference

Fig. 1: Result of durability test. left: using UV-curable resin, right: using PVA solution. (a) initial colored state (b) after 50 cycles of heating and cooling.

Fig. 2: Photographs of the light modulator. (a) colorless state (60°C) (b) colored state (ambient temperature)
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Introduction
Reversible color changing materials are promising technology for various optical devices. We have reported novel light modulating materials imitating the manner of the pigment cells of cephalopods utilizing volume-phase transition properties of polymer gel particles (Fig. 1). In this system, the transmittance of the device is able to be changed according to the change of the light absorption area of colored gel particles. The dispersion of these colored gel particles showed an excellent reversible light modulating ability (Fig. 2). Now we are trying to apply these materials to various practical optical devices.

Materials and Methods
We used N-isopropylacrylamide (NIPAM) gel as a thermo-responsive gel. We used polyvinyl-alcohol (PVA) based UV-curable resin as a material for self-supporting layer.

Optical Property of the Light Modulator
Reversible color changing materials are promising technology for various optical devices. We have reported novel light modulating materials imitating the manner of the pigment cells of cephalopods utilizing volume-phase transition properties of polymer gel particles (Fig. 1). In this system, the transmittance of the device is able to be changed according to the change of the light absorption area of colored gel particles. The dispersion of these colored gel particles showed an excellent reversible light modulating ability (Fig. 2). Now we are trying to apply these materials to various practical optical devices.

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Results
Phase-transition properties in PVA aq. and UV resin

Pigment Cell of Cephalopods

Stimuli

Muscle
Pigment bag
Pigment

Conclusions
We designed and fabricated a light modulator utilizing “gel-in-the-gel” layer in which colored NIPAM gel particles are held in the water-soluble UV resin matrix. The results are as follows.

- Volume-phase transition of colored NIPAM gel particles was observed in cured UV resin (PVA-gel) and the light modulator utilizing this system showed excellent light modulating ability.
- Gel particles and the solvent were held in the resin matrices so tightly that we succeeded in preventing the leak of the solvent.
- The light modulator showed excellent stability under repetitive cycle, because of the prevention of the aggregation among gel particles.
- A flexible light modulator can be fabricated with flexible substrates such as PET film.
- Color change temperature can be controlled using ionic surfactant (SDS).
- The light modulators with a variety of color were obtained by introducing various color pigment in the gel or mixing different colored gel particles.

Future and Outlook
Our group is now trying to develop practical devices taking advantage of the strong points of our material. To be specific,

- Energy-saving Glass (utilizing UCST gel)
- Optical Devices (e.g. Optical switches)
- Display Devices
- Optical Sensors etc.

References
Kokufuta, E.; Zhang, Y. Q; Tanaka, T.; Mamada, A. Micromachines 2013, 26, 1051.