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Brilliant Cosmetic Film for Ambient Displays, with Cholesteric Liquid Crystal

Makoto Ishiguro, Nobuhiko Ichihara, Yujiro Yanai, Michio Nagai, Katsuyuki Takada, Yoichi Suga, and Yoji Ito
Display Materials Research Laboratories, FUJIFILM Corporation
210, Nakanuma, Minamiashigara, Kanagawa 250-0193, JAPAN

Abstract
A brilliant cosmetic film with polymerized cholesteric material (PCM) has been developed. The film features a variety of colors by helical pitch gradients, diffusive texture, and arbitrary color patterns. It hides the display when turned off, and transmits display images when turned on. We believe it could change the display in the Off-state from the conventional black wall to specially designed decorations. In addition, they can be applied to hidden sensors.

Author Keywords
cholesteric liquid crystal; ambient display; sensor; pitch gradient; decoration film

1. Introduction
For many years, the display in the OFF-state generally looks like a black wall. It is not a welcome prospect that these black walls will increase around us. It is preferable to put various decorations on displays at the OFF-state, but conventional decorative films have low transmittance and impair visibility of display images in the ON-state [1][2]. A mirror display has been promoted as an ambient (unnoticed) display when not in use [3]. The mirror display in the OFF-state looks like an ordinary mirror. We considered that a display in the OFF-state needs to express a variety of decorations rather than a mirror. To achieve this, we studied to apply cholesteric liquid crystals.

Cholesteric liquid crystals (Ch-LCs) have selective reflection characteristics. By means of selective reflection of certain wavelengths, various colors can be expressed. Patterning of different wavelength reflection is also possible. In addition, Ch-LCs have the characteristic of reflecting circularly polarized light having the same direction as the helix. Conversely, circularly polarized light in the direction opposite to the helix is not reflected but rather transmitted. Because polarizers are used for displays such as LCDs and OLEDs, the polarization state of the outgoing light is linearly polarized light. Therefore, we had the idea that polymerized cholesteric material (PCM) films can show decorations on displays in the OFF-state without impairing visibility of display images in the ON-state.

This concept is explained in Figure 1. A decorative film comprising with a PCM film and a quarter wave retardation film (QWF)[4] [5] lamination is placed on the outermost surface of the display. In the OFF-state, since external light is reflected by the decorative film, the pattern of the decorative film can be seen. On the other hand, in the ON-state, linearly polarized light emitted from the display is converted into circularly polarized light by the QWF, and passes through the PCM film uninterruptedly. When the helical sense of the PCM film is opposite to the direction of the circularly polarized light, the light for display can be transmitted almost without loss. As a result, it is possible for the display to show a decoration in the OFF-state without loss of brightness of the display in the ON-state. However, if conventional PCM films are used as a decorating material, there are the following problems. (i) The reflected colors are visible only in the specular reflection direction. (ii) Only a few colors can be expressed.

The objectives of this paper are to develop the PCM films that can realize the following applications: (1) ambient displays without impairing visibility of display images in the ON-state, and (2) ambient sensor (IR sensor shield) without hindering passage of IR light.

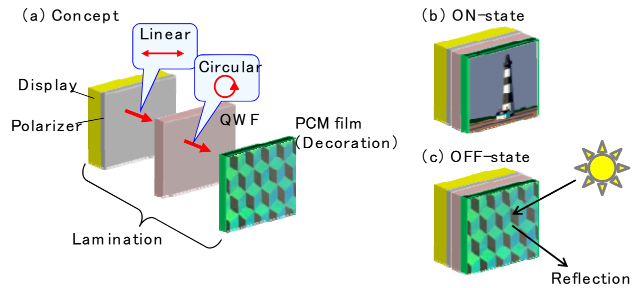

Figure 1. The concept for ambient display with a PCM film.

2. Experiment
We prepared PCM films, comprised of a cellulose triacetate (CTA) film and a calamitic LC layer. When we controlled the angle of LCs by controlling the surface energy of the substrate, and aligned LCs in waves, the PCM films with wave alignment are developed. Here, reflection plane of the PCM films with wave alignment are in waves. For comparison, PCM films with horizontal alignment (non-wave alignment) are prepared by adding molecule azimuth anchoring force of surface treatment.

Integrated reflectance spectrum was measured with a spectrometer V-550 (made by Jasco Ltd.) equipped with an adapter ILV-471. Transmittance spectrum was measured with an UV-Vis-NIR spectrometer (UV-3150, SHIMADZU Corporation).

3. Results
3-1. Viewing angle of reflected light
In general decorative materials, brilliant or matte textures are expressed by controlling the diffusion of the reflected light, as shown in Figure 2. PCM film has the reflective property that is similar to Bragg reflection. The direction of selective reflection of PCM films is determined by the tilt angle of reflection plane. We had the idea that if we change the tilt angles from all horizontal to progressively changing directions with respect to the substrate, the reflected light could be seen from any angle, due to the diffusive characteristics. We found that by changing the surface energy of the substrate, it is possible to control creating a wave alignment of the PCM films [6]. Figure 3 shows photos of PCM films from various directions. The PCM film with wave alignment exhibits diffuse reflection and the reflected color can be

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seen from various directions. Moreover, the PCM film with wave alignment can have both brilliant and matte color characteristics. In contrast, the PCM film with horizontal alignment has specular reflection properties, and the reflected color can be seen only from a specular reflection direction and shows nonuniform reflectivity. As a result, aligning Ch-LC molecules in a wave pattern makes it possible to express brilliant color or matte color, and makes the reflected light visible from any angle.

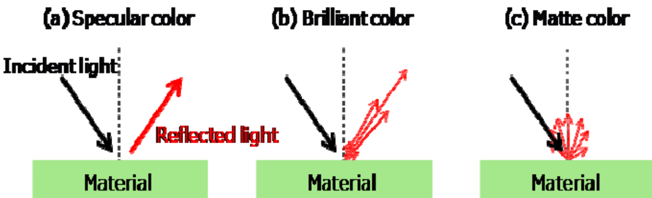

Figure 2. Specular, brilliant, and matte are made by changing the diffusion of the reflected light.

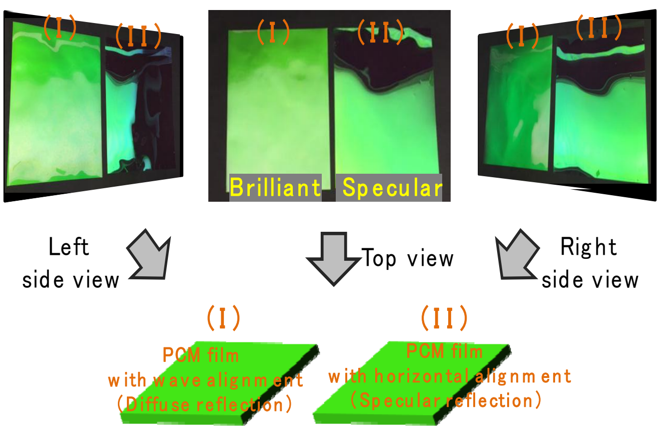

Figure 3. The photographs of PCM films with wave alignment (I) and with horizontal alignment (conventional) (II). The photographs taken from different angles.

3-2. Reflection bandwidth

The half-width of the selective reflection band, called FWHM (full width at half maximum), depends on birefringence (Δn) of the LC. Colors such as blue, green, and red can be easily expressed by Ch-LC layers that contain a single pitch in the film thickness direction. On the other hand, colors such as yellow, cyan, and silver cannot be expressed by a single LC layer. In order to express these colors, it is necessary to increase the selective reflection band. Thus, to increase the colors that can be expressed by PCM films, we decided that it is necessary to change the helical pitch length along the film thickness direction, making a pitch gradient [7-11]. We have reported on color filters using Ch-LCs, achieving selective reflection in the range from blue to red by controlling the helical pitch of Ch-LCs by means of light irradiation [12]. By applying the photosensitive materials controlled by light intensity, we found that a pitch gradient can be induced in the film thickness direction, controlling the helical pitch by means of light. Figure 4 shows the integrated reflectance spectrum of PCM films with a single pitch (conventional) and with a helical pitch gradient. The two measured films have the same thickness. In contrast with conventional PCM films, PCM films with a helical pitch gradient have the characteristic of reflecting over a broad wavelength band.

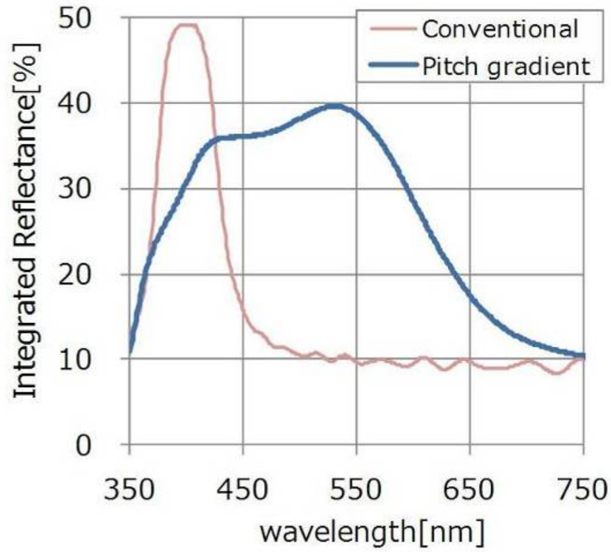

Figure 4. Integrated reflectance spectrum of PCM films with a single pitch (conventional) and with a helical pitch gradient. The two measured films have the same thickness.

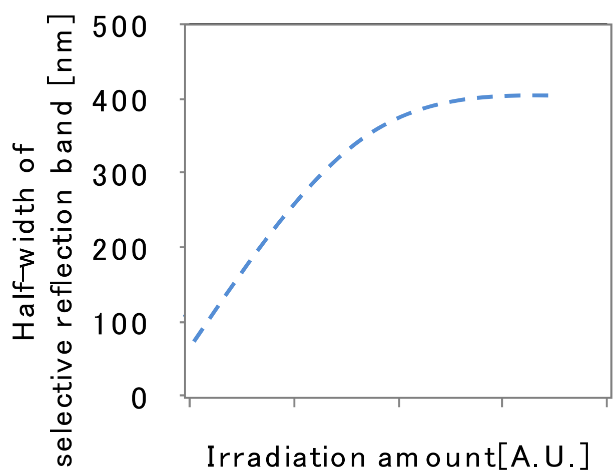

Figure 5. Half-width of selective reflection by UV-irradiation.

Selective reflection band can be controlled by the irradiation amount of UV light. One example is shown in Figure 5. With our helical pitch gradient technology, we can make PCM films that reflect the whole range of visible wavelengths.

Figure 6 shows decoration films produced with one PCM layer. The PCM films with a helical pitch gradient can express various colors such as yellow, cyan, and silver. These colors cannot be expressed by Ch-LC layers contain a single pitch. In addition, since we can control the helical pitch length in the film thickness direction by means of light, we can create various color patterns by patterning the amount of UV light applied.

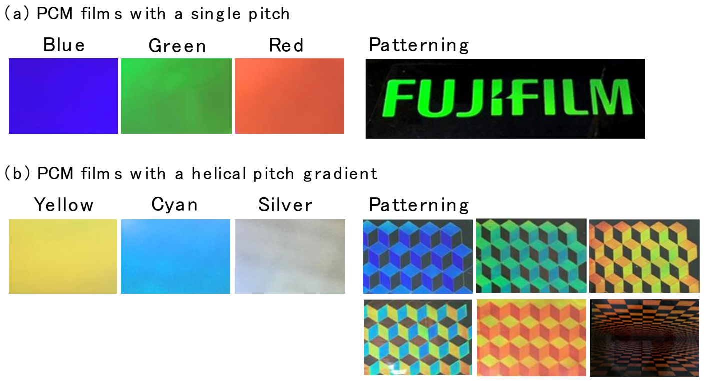

Figure 6. The photograph of FF-decoration films made from one PCM layer. The photographs were taken with the films placed on black paper.

4. Application of brilliant cosmetic films

4-1. Ambient display

Figure 7(a) shows an example in which the display of a car navigation system or a tablet PC is decorated with our patterned PCM film. In the OFF-state, the display doesn't seem to be present, and the pattern of our PCM film blends in with the surroundings. On the other hands, in the ON-state, the display image is fully visible, unhindered by that film.

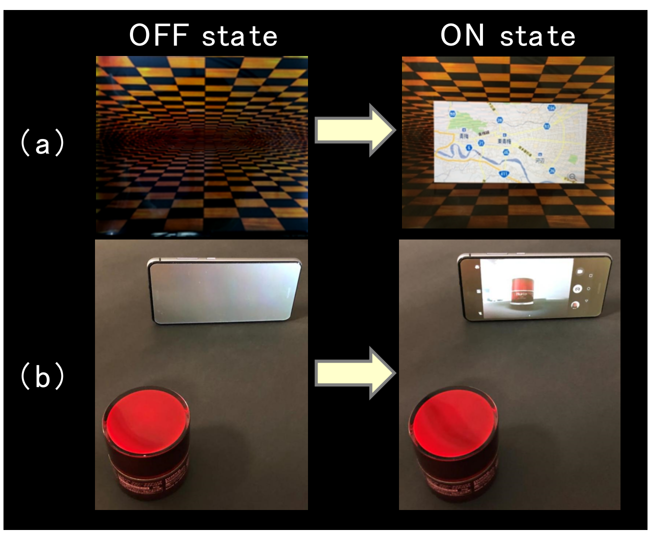

Figure 7. Example of display decorated with our PCM films. (a)The PCM film with a helical pitch gradient is mounted on the car navigation system or a tablet PC. (b)The PCM film with a helical pitch gradient is mounted on the smart phone surface.

Figure 7(b) shows an example of decoration covering a smart phone. The PCM film with helical pitch gradients that reflect the whole range of visible light is mounted on the smart phone surface. Figure 8 shows transmittance spectrum for linear polarized light and integrated reflectance spectrum at normal direction. Measured sample was the decoration film for the smart phone (as shown in Figure 7(b)) comprising with the PCM film and the QWF lamination. The transmittance and integrated reflectance at oblique direction show the same properties. In the OFF-state, the display and the camera cannot be seen at both normal direction and oblique direction, because of reflection of the PCM film. On the other hand, in the ON-state, our PCM films do not impair the display images and camera detection. Thus, our PCM film greatly contributes to the spread of ambient displays.

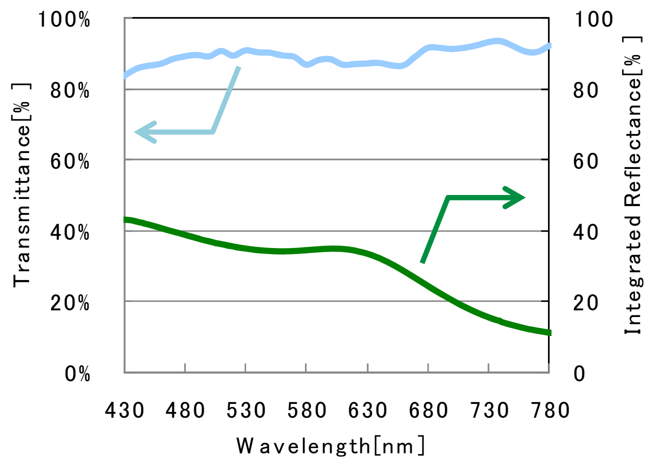

Figure 8. Transmittance spectrum for linear polarized light, and integrated reflectance spectrum. Measured sample was the decoration film for the smart phone, comprising with the PCM film and the QWF lamination.

4-2. Ambient sensor (IR sensor shield)

Besides display applications, our PCM film can be applied for sensors. As shown in Figure 9, by combining a visible light cut filter and our PCM film which reflects visible light, it is possible to decorate the IR sensor without hindering passage of IR light. The visible light cut filter looks like black wall, like a conventional display in the OFF-state. Since the conventional decoration film absorbs IR light, it is visually recognized by the IR sensor, which may interfere with the sensing function. Figure 10 shows transmittance spectrum and integrated reflectance spectrum of the IR sensor shield comprising with the PCM film and the visible light cut filter lamination shown in Figure 9. Our PCM film transmits the detection wavelength of the sensor. As a result, the patterns can be fabricated without affecting the sensor detection. That means the sensor doesn't recognize the patters. In contrast, the patterns can be seen from the outside of the sensor. We consider the PCM film can greatly contribute to future sensors.

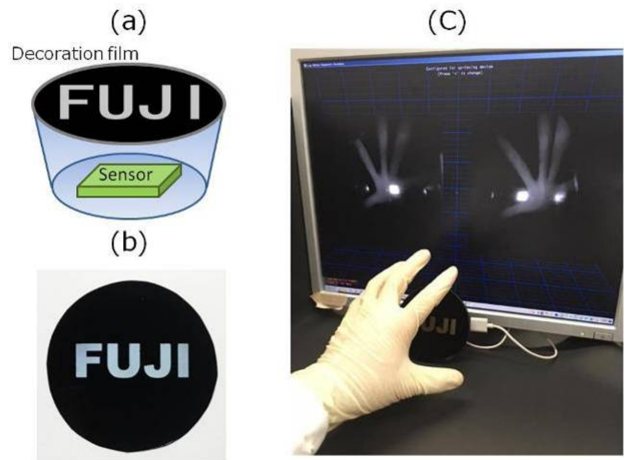

Figure 9. Application of our PCM film to IR sensor shields. (a)Schematic image of the sensor placed behind the decoration film with the PCM film. (b)The sensor cannot be seen from the outside. (c)The decoration films do not impair the function of sensors.

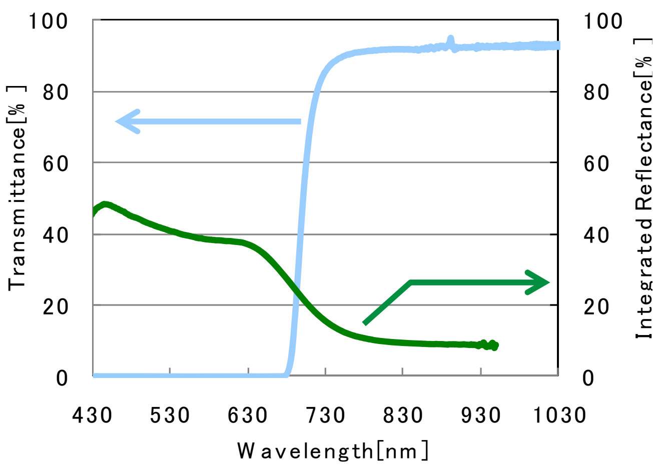

Figure 10. Transmittance spectrum and integrated reflectance spectrum of the IR sensor shield comprising with the PCM film and the visible light cut filter lamination.

5. Conclusion

We have successfully developed cosmetic films with polymerized cholesteric materials (PCM). The films feature a variety of colors by helical pitch gradients, diffusive texture, and arbitrary color patterns. The films can be applied for various application, and add new value. When the PCM films are applied to displays, they could change the display in the Off-state from the conventional black wall to specially designed decorations. In addition, when they are applied to hidden sensors, we can decorate the special patterns to the sensor. The patterns made with the PCM film can be seen from the outside of the sensor, while the sensor cannot visually recognize the patterns. We consider that our PCM films could greatly contribute to future displays and sensors.

6. Acknowledgments

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