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Cellophane as a half-wave plate and its use for converting a laptop computer screen into a three-dimensional display

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It was experimentally verified that an ordinary 25-μm-thick cellophane sheet possesses properties of a wide wavelength spectrum half-wave plate. Moreover, cellophane displayed superior performance when used for rotating the direction of polarization of white light than a commercially available half-wave plate with a specified wavelength. The retardance of the cellophane was measured to be 170°. The availability of a half-wave plate of an extra large size with low cost opens up usages for large size displays. As an example of its application, an ordinary screen of a laptop personal computer was converted into that of a three-dimensional display by the cellophane half-wave plate. It may be added that the price per square cm^2 of the cellophane half-wave plate is about 1/3500 of that of a commercially available half-wave plate.
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I. INTRODUCTION

Cellophane, being impermeable to gases, grease, or bacteria, is widely used as wrappers or bags for packaging food and merchandize.

Cellophane is birefringent and can be used as a half waveplate;[1] but to the best of the author's knowledge, no one has either measured its retardance or has discovered that an ordinary 25-μm-thick cellophane wrapping paper functions as a wide wavelength band (white light) half-wave plate better than a commercially available half-wave plate specified for a single wavelength.

The article reports the measurement method and measured retardance of the cellophane sheet. Comparison of the performances were made of the cellophane and a commercially available half-wave plate when used for white light.

An example will be shown of how such a cellophane sheet is used to convert a two-dimensional (2D) screen of a laptop personal computer into a three-dimensional (3D) display.

II. MEASUREMENT OF THE RETARDANCE OF CELLOPHANE

Cellophane is fabricated by protruding alkaline viscose solution through a narrow die into an acid bath. Because of the unidirectional strain during the protruding process, cellophane is birefringent, and the index of refraction measured by light polarized in one direction is different from that measured by light polarized in the orthogonal direction.

The retardance of the cellophane sheet was determined from the change in the state of polarization of the light after transmission through the sample. Pertinent choices of the orientation of the fast axis of the birefringent sample and the direction of the polarization of the incident linearly polarized light significantly simplify the calculation of the retardance from the measured quantities.

If the fast axis of the cellophane is chosen horizontally and the direction of polarization of a linearly polarized incident light, at 45° from the horizontal direction, as shown in Fig. 1, then the major axis of the elliptically polarized emergent light stays always either at 45° or 135° from the horizontal axis. Moreover, the ellipticity ε of the emergent light monotonically increases with the retardance Δ of the sample; more specifically, their relationship is

$$\Delta = 2\beta, \tag{1}$$

where

$$\tan\beta = \varepsilon = \frac{b}{a}, \tag{2}$$

a, and b are the lengths of the major and minor axes of the elliptically polarized emergent light. The proof of Eqs. (1) and (2) using the circle diagrams is found in Ref. 2.

Figure 2 shows an experimental arrangement. The light passes through the elements in the following order: linearly polarized HeNe laser light source, cellophane sample, rotatable analyzer, and light detector.

The direction of polarization of the source light was set at 45° from the horizontal direction. The cellophane sample was held with its rolled direction (namely, the longer dimension of the rolled cellophane) vertical. The analyzer was held in a rotatable holder with angular graduations. The emergent light was detected by an Anritsu optical power meter model ML9001A.

The locus of the intensity of the emergent light was measured as the analyzer was rotated. The output from the light detector was the light power in watts and the amplitude of the light was calculated by taking the square root of the measured intensity. The result is plotted in Fig. 3 to obtain

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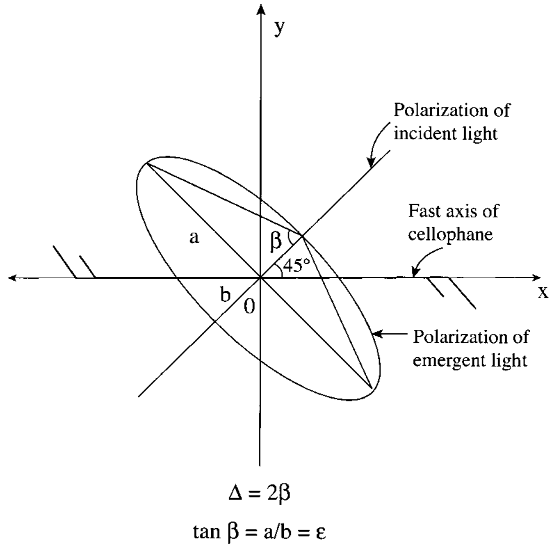

FIG. 1. Conversion of linearly polarized incident light to elliptically polarized light by a retarder.

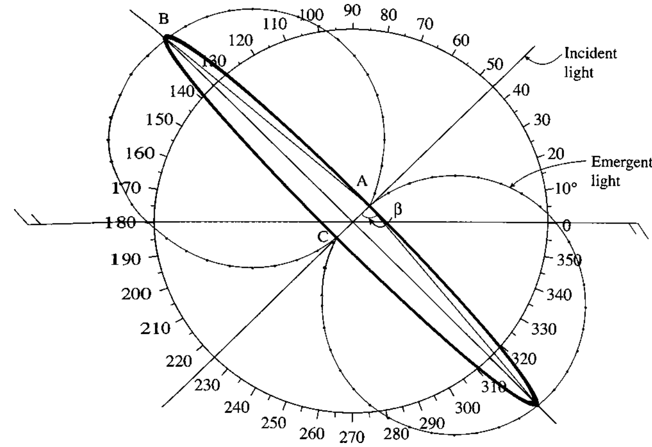

FIG. 3. Measured output from the detector as the analyzer was rotated.

the envelopment. The envelopment provides the ellipse of the polarization of the emergent light. The determined ellipticity was $\varepsilon=11.6$ and $\beta=85.1°$ and from Eq. (1) $\Delta=170.2°$, which is about 95% of the retardance of the half-wave plate.

Some of the practical applications do not require a precise 180° retardance. An example of satisfactory use of cellophane as a means of converting the display of a plain ordinary laptop computer into a 3D display is reported next.

III. 3D DISPLAY IMPROVISED BY COMBINING A CELLOPHANE HALF-WAVE PLATE WITH A LAPTOP COMPUTER

Stereoscopic viewing is realized by separately manipulating what the right eye sees from what the left eye sees. Orthogonally polarized left and right scenes are separated by wearing a pair of glasses of orthogonal polarization.

A laptop computer was improvised to display images of a stereoscopic pair with orthogonal polarization. Almost all laptop computers use a liquid crystal display. The liquid crystal display is composed of polarizer and analyzer sheets that sandwich the twisted nematic (TN) liquid crystal pixels whose light transmission is controlled by the applied signal voltages.[3] It is this analyzer that makes the light from the laptop computer linearly polarized. Light from our laptop computer is polarized at 45° from the horizontal direction. In order to display the images of a stereoscopic pair with orthogonal polarization, the direction of polarization of light from one half of the laptop computer screen has to be rotated by 90° to 135° from the horizontal direction. The half-wave plate can be used to change the orientation of polarized light. The direction of polarization of the emergent light looks like a mirror image with respect to the fast axis of the half-wave plate. The light from the laptop computer polarized at 45° can be converted into light polarized at 135° by covering the screen with the cellophane half-wave plate with its fast axis vertical. As shown in Fig. 4, only the right half of the laptop screen was covered by the cellophane half-wave plate.

Thus, the light from the left half of the screen is polarized at 45° while the right half, is at 135°. The emergent lights from the two halves of the screen are othrogonally polarized. Now, a portion of the screen that the right eye sees can be separated from that the left eye sees by wearing a pair of glasses with polarizers of orthogonal polarization axes. The transmission axis of the polarizer of the right eye is set at 45°, and the right eye sees only the left half of the screen and cannot see the right half of the screen. On the contrary, the transmission axis of the polarizer of the left eye is set at 135° and the left eye sees only the right half of the screen.

In order to see the effectiveness of blocking one half of

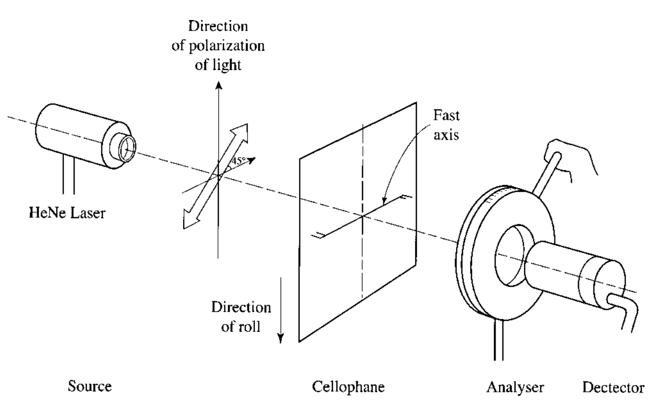

FIG. 2. Arrangement for measuring the retardance of cellophane.

FIG. 4. Cellophane used for converting the laptop computer to 3D.

FIG. 5. (a) (Color) Stereoscopic pair photographed through the right eye polarizer of the polarizer glasses. (b) Stereoscopic pair photographed through the left eye polarizer of the polarizer glasses. (c) Stereoscopic pair made of a cover page of a magazine, which was photographed without polarizer glasses.

the stereoscopic pair, the pair was photographed through the polarizer sheet of the polarizer glasses. Figure 5(a) was photographed through the right eye polarizer of the polarizer glasses, and Fig. 5 (b) through the left eye polarizer of the polarizer glasses. Figure 5(c) was photographed without polarizer glasses.

Thus, by wearing polarizer glasses, the right eye sees only the left picture and the left eye, only the right picture. The lines of sight of the eyes are crisscrossed. The right half of the screen in Fig. 5(a) that was covered by the cellophane sheet is not completely dark but it was dark enough for the purpose of stereoscopic viewing.

The effectiveness of blocking the screen of the cellophane sheet was compared with that of a 2 in.$\times$2 in. square commercially available half-wave plate specified for a wavelength $\lambda = 0.62\ \mu$m. Figure 6 demonstrates that the right window covered by the commercially available half-wave plate is lighter and is not as effective at blocking the light as the cellophane half-wave plate is. This proves the cellophane half-wave plate is superior in the case of white light. Some irregularity is recognized in a cellophane sheet (Cello Gift Wrap by Lewiscraft) but did not interfere with the function of stereoscopic viewing.

A stereoscopic pair was generated out of a painting that appeared on the cover page of a magazine. First, two identical copies of the painting were displayed side by side on the computer screen. Then, portions of the objects in the right picture were manipulated. This manipulation is shown in Fig. 5(c). The object desired to be seen further back was shifted to the left and object desired to be seen closer to the front was shifted to the right (the effect of these shifts is explained in the Appendix).

Elliott's stereoscopy,[4] whose eye sight paths are crisscrossed, has been mentioned so far, but Wheatstone stereoscopy,[5] which is without crisscross, was also tried, but the former provided a better parallax effect. Even if the scene is a primitive type of computer graphics, a dramatic 3D effect was observable. In addition to the aforementioned computer graphic methods, a pinhole stereo camera was constructed and a stereoscopic pair was fabricated photographically. The photograph was displayed on the cellophane covered laptop screen. A realistic 3D image was observed.

IV. DISCUSSION

It was demonstrated that a plain ordinary cellophane sheet can play the function of a wide wavelength band half-wave plate. The value of the retardance was measured at $\lambda = 0.6328\ \mu$m to be 170.2°.

Moreover, the performance of a cellophane half-wave plate was proved superior to a commercially available half-

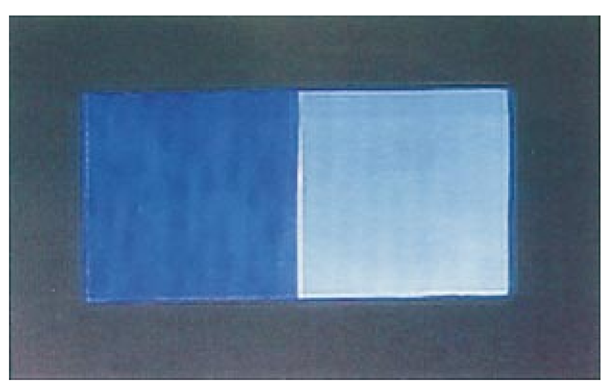

FIG. 6. (Color) Effectiveness of blocking the screen is compared between the cellophane sheet on the left and commercially available half-wave plate on the right.

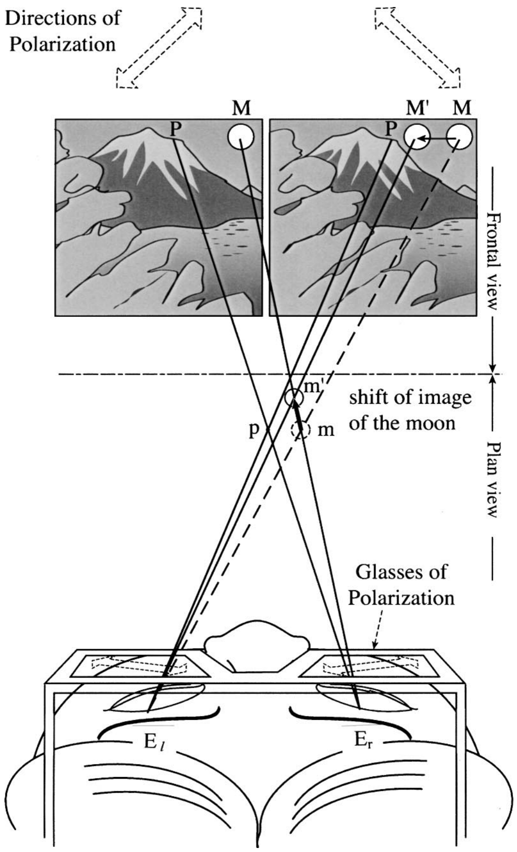

FIG. 7. Principle of the 3D display of the crisscross stereoscopic pair.

wave plate in the case of a white light application. The availability of a large size half-wave plate at a minimum cost made it possible to construct a 3D display out of a laptop computer. Such a laptop 3D display may be useful for gaming, scientific, and medical imaging applications or as a means of a quick look at computer graphics.

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APPENDIX: FABRICATION OF A STEREOSCOPIC PAIR

Figure 7 is for explaining the light paths for an observer looking at the stereoscopic pair. Figure 7 is a composite of the frontal view in the upper portion and the plan view in the lower portion. Let us consider the light path of the mountain point P. Light from P in the left picture reaches the right eye E_r, and P in the right picture, reaches the left eye E_l. The observer recognizes the existence of P at the intersection p of the two crisscross lines. It is the same with the moon M.

If there were a light emitting from point p, the way to reach the observers eyes would be along diverging lines starting from point p to each one of the observers eyes. To the eyes, whether the line started from P or p does not make any difference as long as the light looks as if it is diverging from point p. The eyes recognize the existence at the point where the divergence of the light starts. It is the same with the moon. The observer recognizes the existence of M at the intersection m but not at M.

Points p and m are located at the same distances from the eyes, but these distances can be changed by shifting the position of M. As the moon is shifted toward the left (namely toward the mountain) the intersection m' keeps moving away from the observer and the moon looks further away from the observer than the mountain. If, however, on the contrary one wants the moon to look closer, the moon should be shifted toward the right (namely, away from the mountain).

We want the foreground fern to look closer and the fern portion has been shifted to the right with respect to the mountain.

[1] E. Hecht and A. Zajac, *Optics* (Addison-Wesley, Reading, MA, 1974), p. 249.
[2] K. Iizuka, *Elements of Photonics* (Wiley, New York, 2002), p. 449.
[3] K. Iizuka, Opt. Photonics News **13**, 12 (2002).
[4] A. W. Judge, *Stereoscopic Photography: Its Application to Science, Industry and Education* (Chapman and Hall, London, 1950).
[5] T. Okoshi, *Three-Dimensional Imaging Techniques* (Academic, New York, 1976).