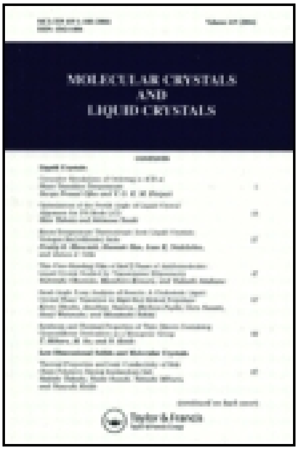

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Investigation of Anisotropic Scattering Films with Unique Functions Such as Light Scattering Polarizer

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We have succeeded in making an optical film whose scattering intensity depends on the polarization direction of incident light. We evaluate and discuss the optical properties of this film based on the results of optical simulation.

Keywords: anisotropic scattering; phase separation; Mie theory

1. INTRODUCTION

Recently, the development of LCDs has been carried out enthusiastically. Various operating modes and panel configurations are devised for improving the display quality, decreasing the power consumption, weight and film thickness, etc. In these tendencies, functions such as control of scattering characteristics, precise control of the polarization state, etc., are required for LCD-related materials for the purpose of increasing the efficiency with which the incident light is modified by the device.

The non-absorption type polarizer[1][2][3] is devised to overcome disadvantages of absorption type polarizers i.e. low polarization efficiency of light and heating due to the absorption of light.

Figure 1 shows the principle of anisotropic scattering film. This dispersion by the optically anisotropic material is just like that by a birefringent crystal material in an isotropic matrix material. The refractive indices of two materials are matched in the vertically polarizing direction shown in the figure, while they are different from each other in the horizontally polarizing direction. The following unique optical character appears, i.e., the polarizing light vibrating in the horizontal direction, is scattered at the interface of materials because of the difference of the

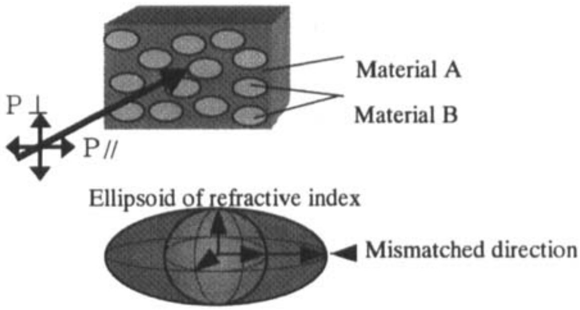

FIGURE1. Principle of anisotropic scattering film.

refractive indices, while the vertically polarized light is transmitted without scattering. Therefore, this film can be applied to a " Scattering Polarizer ". The first scattering polarizer was published by E.H. Land in 1938[2] . He is also an inventor of an absorption type polarizer. Inorganic crystals[2] and PDLC (Polymer Dispersed Liquid Crystal) sheets were stretched uniaxially[4] as birefringent materials at the initial stage of research. Because of the development of polymer chemistry, it has become possible to synthesize polymers having various refractive indices and anisotropy of refractive indices, and to prepare films with high practicality by a simple manufacturing method employing phase separation behaviors as described in this report. In addition, the unique features of the film which shows the scattering anisotropy against polarized light as well as features of a polarizer are clarified on the basis of experiments and simulations.

2. EXPERIMENTAL

2-1. Sample Preparation

The scattering anisotropic film was obtained by uniaxially stretching a film consisting of two kinds of materials which have different birefringent property one another and having an appropriately dispersed structure. The phase separation of a blending polymer was used to form the dispersed structure. The actual procedure is as follows.

① Select transparent materials which are not soluble in each other, and dissolve them in a common solvent.
② Cast this solution on the flat plate.
③ Exfoliate films from the flat plate, and completely dry the solvent.
④ Orient the polymer by stretching these films.

The scattering anisotropy appears in some kinds of materials. In the following section, an actual film consisted of acrylonitorile-styrene copolymer (AS) resin and polyallylate (PAR) resin were discussed. In this case, micro-domains formed by AS resin are dispersed in matrix PAR resin. AS resin have low birefringence compared with PAR resin. 20 wt%-solution was prepared by dissolving each resin in dichloroethane at a weight ratio of 2 : 8 (= AS : PAR). This solution was casted on a PET (Polyethylene Terephthalate) film allowed to stand on the flat plate by using an applicator with a gap of 200 μ m. After the solvent was dried naturally for about 5 minutes at room temperature, the dispersed film was removed from PET and was dried for one hour at a temperature of 50°C. This film was stretched mechanically and uniaxially at a room temperature.

2-2. Characterization

(1) Refractive Index

The refractive index of each material was measured by means of the following methods. A film consisting of a single component was prepared, and average refractive index n_{iso} was measured with an Abbe refractometer in state where the film has not yet been stretched. The film was stretched by an arbitrary magnification, and the phase difference $\Delta nd = | n_x - n_y | \cdot d$ was measured with a polarization spectrophotometer. The refractive index in each direction was calculated considering the condition of uniaxially stretching i.e. $n_y = n_z$. All of the values were converted into the value of 550nm in consideration of the dispersion of wavelengths in order to make a comparison and studies.

(2) Dispersed Size

Figure 2 shows a photograph of a fabricated sample when it is placed between cross polarizers of a polarization microscope at an angle of 45°. This image correspond to the difference of color caused by the phase difference. From this photograph, many dispersed phase composed of isotropic material with a major axis of about 10 μ m are seen.

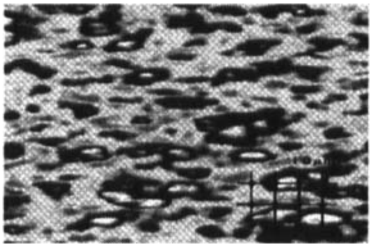

FIGURE2. Micrograph of sample in clossed polarizers.

(3) Film Thickness

The thickness of films with uniaxial orientation was measured by using a micrometer. The thickness was changed by stretching. For example, a sample thickness reduced to 0.85 times by stretching at room temperature when the stretched ratio was 1.5. In this paper, the film thickness measured after stretching were used.

(4) Particle Concentration

The concentration of dispersed particles was calculated from the particle sizes, the weight ratio and the specific gravity of each materials.

2-3. Measurement

In order to measure the scattering intensity, the transmittance versus the incidence of the white light was measured. A goniophotometer was used to measure the angular properties of the scattered light. A sample was put between glass plates and matching oil of refractive index was injected between each layer to suppress the surface reflection. The optical characteristics were measured using polarized light with the polarization axis parallel and perpendicular to the orientation axis of the sample.

3. RESULT

Figure 3 shows an experimental result of the rectilinear transmittance. It is confirmed that the film has a function of a polarizer. The polarization

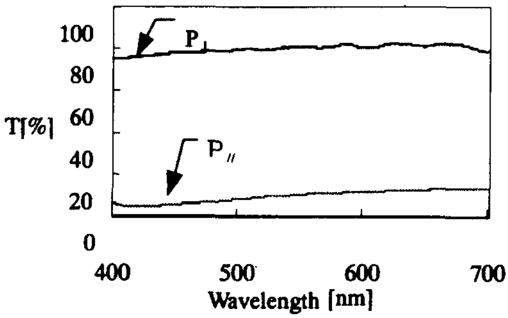

FIGURE3. Transmittance of sample film as a function of wavelength.

efficiency is 88%. The example of this result indicates that when polarizing direction is parallel to the stretching direction, the incident light scatter intensively.

Figure 4 shows of the measurement of the angular properties of the scattering. It shows that the angular distribution of the scattering depends on the incident polarizing direction. When the polarizing direction is parallel to the stretched axis, the incident light scatters to a wide angle.

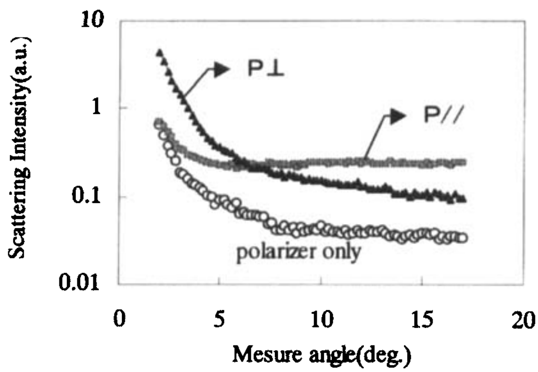

FIGURE4. Angular property of scattering for normally incident light.

4. SIMULATION

Particle diameter, refractive index for the polarization directions of parallel and perpendicular to stretching were estimated roughly from the experimental results. Systematic research on behaviors of the light scattering property by small particles has already been clarified[5]. When the size of particles is very small, scattering characteristics can be estimated by means of Rayleigh's scattering theory, but when it is sufficiently larger than the wavelength of light, the scattering intensity can be treated with geometrical optics. The dispersion size in this research, however, lies between the above mentioned two cases. Thus, numerical simulations of multiple scattering phenomena were made by using Hartel's approximation[6] and Mie theory whose solution was found strictly by using boundary conditions obtained from Maxwell's equation. We calculated the multiple scattering intensity by the following equation

$$I_{scat}(\theta) = \sum_{k=0}^{\infty} Q_k f_k(\theta) \tag{1}$$

where Q_k is *k*th scattering intensity function and $f_k(\theta)$ is *k*th scattering angular distribution function. The equation was calculated numerically by computers. As for the dispersed size, difference of refractive indices between two materials, film thickness, and particle concentration, the previous results were used.

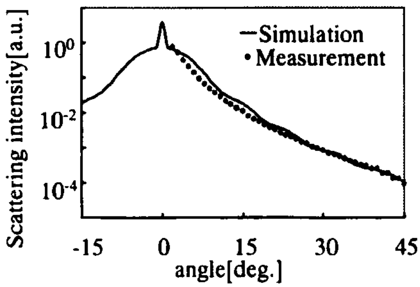

FIGURE5. Comparison of simulation and measurement for the angular dependence of scattering intensity, where the scattering intensity is normalized by the value at the angle of 0° .
(Film thickness:40 μ m, Particle concentration:25%, Wavelength:550nm, Difference of refractive index:0.08, Particle dimeter:7.0 μ m)

An example of the scattering property for a typical sample film is shown in figure 5 comparing with the theoretical simulation. Both results agree well to each other. The validity of the simulation was confirmed from this figure.

In this simulation, it is assumed that the particle is sphere and back scattering is sufficiently low. This condition is satisfied in our experiment, while in the case of thick film or strongly stretched film this condition is not satisfied.

5. DISCUSSION

Figure 6 shows the calculated results of the haze when particle diameter and the difference of refractive index between dispersed material and matrix material are changed respectively. The other parameters are fixed to values of the actually used material in the experiment. It is found that the haze largely varies according to the particle size and difference of refractive index. The star marks in Figure 6 show the experimental values of haze for the incident light polarized parallel ($P_{//}$) and perpendicular ($P_{\perp}$) to the stretched direction of the film, respectively. In this sample, the differences of refractive index between a matrix polymer and a dispersed particle, Δn, is 0.01 and the diameter of a particle, d, is 7 μ m for the polarized light $P_{//}$, and they are respectively 0.05 and 2 μ m for the polarized light $P_{\perp}$. The value of haze measured by polarized light which corresponds in each direction was $P_{//}$: 9% and $P_{\perp}$: 81%. These experimental values agree well with the calculated values in a simulation as shown in Figure 6. It is proved by the

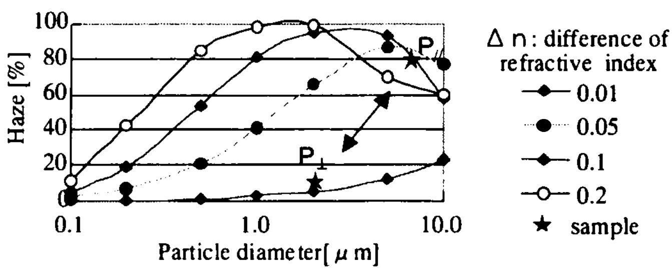

FIGURE6. Dependence of dispersed size and difference of refractive index between dispersed material and matrix material.
(Film thickness:40 μ m, Particle concentration:40%, Wavelength:550nm)

fabricated sample in our experiment that the anisotropic scattering was obtained to some extent.

From the view point of application, the scattering for $P_{//}$ is strong enough, while that for $P_{\perp}$ is not sufficiently weak. In order to get much larger anisotropy of scattering, the scattering for $P_{\perp}$ must be suppressed by decreasing the difference of refraction index for $P_{\perp}$ as small as possible, and by decreasing the diameter of a particle.

6. CONCLUSION

We succeeded in making a novel film dispersed with particles using the phase separation phenomenon. This film has strong anisotropy of the scattering property caused by uniaxially stretching.

It has confirmed that the anisotropy of the scattering of this film agrees well with the simulation result based on the Mie's theory.

Many application using this film can be considered. For example, if the film with the very large anisotropy of scattering is applied to an usual LCD back light system, it is possible to recycle the unused polarized light, and the utilized light efficiency becomes more than 50%.

We have clarified a guideline for designing the anisotropy of scattering suitable for practical application. The most important parameters for controlling the anisotropy of scattering are the diameter of the dispersed particle and difference between refractive indices for the two polarized directions. Practical film with large anisotropy of scattering is under development in terms of selection of materials, film forming methods, etc.

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