Circular Polarizers for Reflective LCDs

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Abstract

Characteristics of reflective LCDs, which have gained a lot of notice in recent years, rely largely on optical design of circular polarizers and the quarter-wave plates, as a component. Important design includes wavelength dispersion, viewing angle, uniformity of display and matching of refractive index. Our work has contributed to improving performance of reflective LCDs by enhancing the characteristics of polymer film using stretching and optical lamination technologies.

To design that offers higher contrast and wider viewing angle, we have discovered that it is necessary to control viewing angle variation of the polarizing axis in order to compensate for the viewing angle of the polarizing film as well as the optical anisotropic properties of liquid crystal. Applying this technology to circular polarizers used for reflective LCDs enables design of wide viewing angle circular polarizers.

In order to realize higher contrast for reflective LCDs, it is also necessary to design other optical materials including polarizing films. For design of hybrid optical film, it is particularly necessary to reduce surface reflection and interface reflection. This paper also reports our findings concerning this topic.

1. Introduction

The reflective LCD has recently become an especially important device for portable information terminals. LCDs using optical film containing circular polarizers on one side have become the mainstream for reflective LCDs, while performance of circular polarizers greatly affects image quality of LCDs.

A liquid crystal display is a device that modulates linearly polarized light by birefringent anisotropic properties of liquid crystal. Even if the liquid crystal mode varies, retardation film would be an important optical material to compensate for birefringent anisotropic properties of liquid crystal. A material that modulates polarized light, retardation film can also control variation due to viewing angle of the polarizing film, that is, the viewing angle of polarization axes. Retardation film would therefore be an important material for designing liquid crystal displays from the standpoint of polarization control as well.

In order to further enhance contrast, it is important to combine surface treatment layer technology for reducing surface reflection and refractive index matching technology for reducing interface reflection.

2. Retardation film technology

2.1 Wavelength dispersion control

It has already been reported that there are three ways to control wavelength dispersion characteristics of retardation film. Those are:

1. Determining wavelength dispersion characteristics according to retardation film raw materials [1)]
2. Controlling wavelength dispersion characteristics by laminating retardation film with differing wavelength dispersion [1)]
3. Controlling wavelength dispersion by laminating retardation film with the same wavelength dispersion [2)]

Fig. 1 shows difference in wavelength dispersion of retardation film according to type of polymer material itself and Fig. 2 shows the method of controlling wavelength dispersion by laminating retardation film with differing wavelength dispersion.

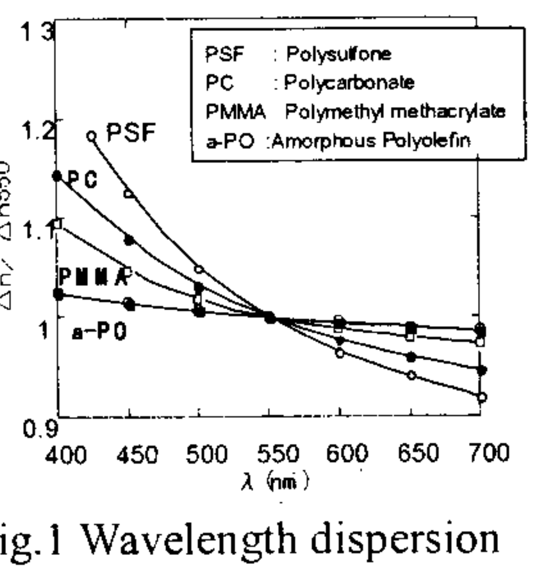

Fig.1 Wavelength dispersion of Δ n in stretched polymer films.

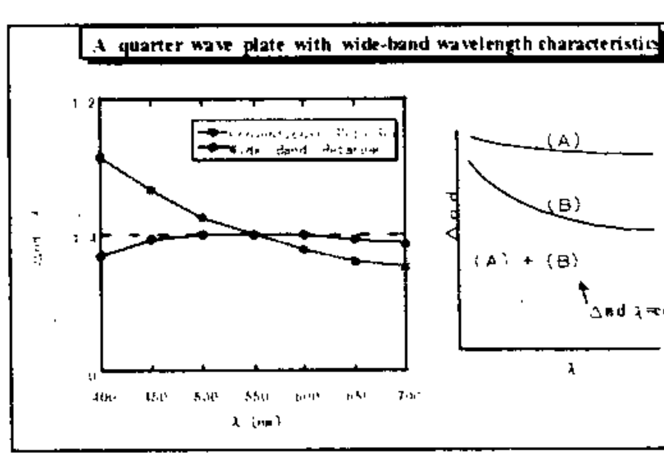

Fig.2 A quarter wave plate with wide-band wavelength characteristics

Wavelength dispersion characteristics of circular polarizers used for reflective LCDs largely affect display performance including display contrast and color. Display of black is determined by the shielding properties of circular polarizers.

The method of controlling wavelength dispersion by stacking layers of retardation film with the same wavelength dispersion is used for this type of display, and circular polarizers have been improved enough for practical use as wide-band circular polarizers.

Fig. 3 shows the principle of preparing circular polarizers to be wide-band type using this method and shielding properties of circular polarizers.

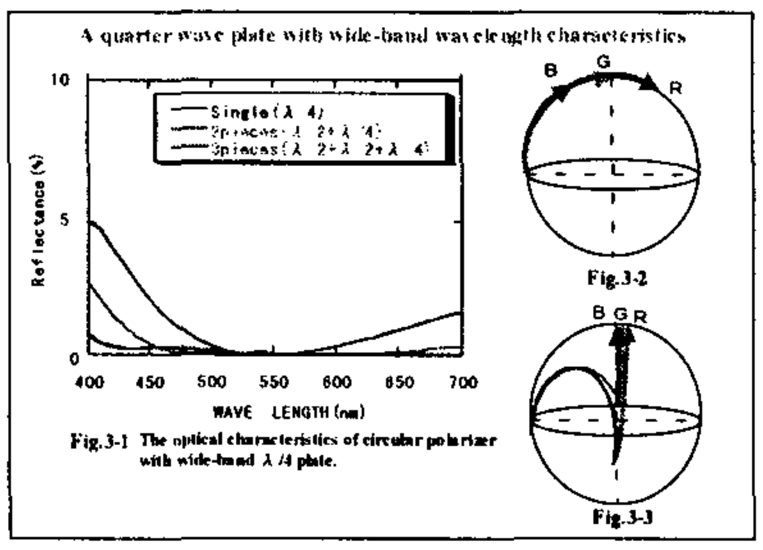

Fig.3 Principle of circular polarizers to be wide-band type and shielding properties of circular polarizers.

Fig. 3-1 shows the results of measuring optical properties with a wide-band circular polarizer placed on a reflector. Favorable shielding characteristics were obtained in all areas off visible light for a configuration of three retardation plates ($\lambda/2$) + ($\lambda/2$) + ($\lambda/4$).

The Poincare sphere of Fig. 3-2 shows the path of converting linearly polarized light to circular polarized light using a quarter-wave plate by RGB. Fig. 3-3 shows the path using half-wave and quarter-wave plates. The figure shows RGB gathering at the pole, thus widening the band.

2.2 Viewing angle control

In the case of retardation film that appears birefringence by stretching polymer film, various types of index ellipsoids that control 3D refractive indices can be obtained.

We have established and improved for practical use technology for both uniaxial and biaxial stretching in not only in the X-Y direction within the plane, but the thickness (X-Z) direction as well

Fig. 4 shows the various types of retardation films obtained through 3D refractive indices control by the stretching method. Retardation film obtained by these stretching technologies includes four types of uniaxial film and three types of biaxial film.

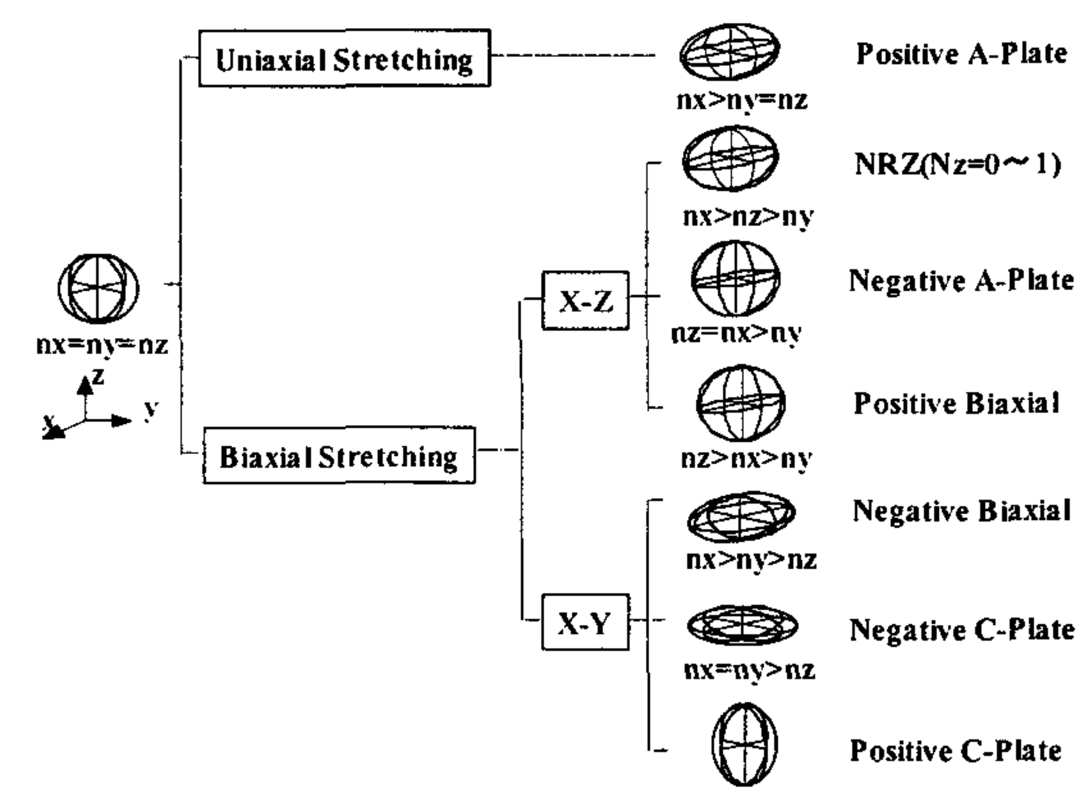

Fig.4 3-D refractive indices control by multi-axis stretching.

The uniaxial type goes by the generic names of negative A-plate, positive A-plate, negative C-plate and positive C-plate.

The biaxial type includes negative biaxial, positive biaxial and our own original NRZ type with two optical axes running parallel to the plane.

Retardation film using these technologies is important for enhancing viewing angle characteristics of liquid crystal displays.

Retardation film is used for the purpose of controlling (modulating) polarized light. Retardation film that control 3D refractive indices are effective for 3-D control of polarized light. It is also well known that retardation value of retardation film varies along with viewing angle. The direction of the fast axis for example changes along with viewing angle. We proposed the Nz factor as an index for expressing the relationship of the 3D refractive indices in 1991, and the Nz factor is still used as the standard index. Variation of the fast axis is related to the Nz factor. ($Nz = [nx - nz] / [nx - ny]$: nx is the main refractive index within the plane, ny is the main refractive index perpendicular to nx, and nz is main refractive index in thickness direction) Please see Fig. 5 .[3]

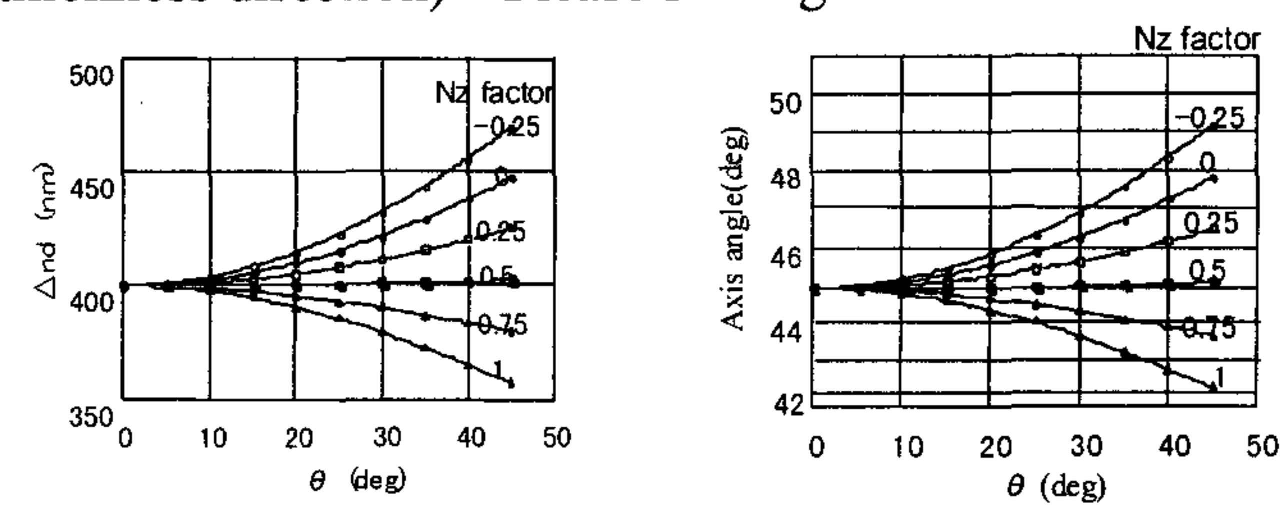

Fig.5 Viewing angle characteristics of NRZ type retardation film

3. Circular polarizers

Application of circular polarizers to transparent

displays and self-illuminating O-LED and FED displays is being studied as well as application to reflective displays.
With the transparent type, we are studying ways to improve on drop in aperture ratio due to discrimination particular to multi-domain orientation.
Circular polarizers are used for self-illuminating displays from the standpoint of prevention of reflected light.

Characteristics required of circular polarizers are as follows:
1) Wide band (wavelength dispersion)
2) Wider viewing angle
3) Higher reliability
4) Higher contrast
Circular polarizers are as follows.

1) Wide band
Quarter-wave plates that provide circular polarization over the entire visible light range can be designed by optimizing their wavelength dispersion.
While the wavelength dispersion of Δn is a characteristic value of each polymer material, ideal circular polarizers are hardly developed by simply selecting polymer materials.
Fig. 1 shows wavelength dispersion characteristics of polycarbonate (PC) and amorphous polyolefin (a-PO) retardation film.
Fig. 6 shows the characteristics of a wide-band quarter-wave plate consisting of retardation film of these materials.
As for the two-layer wide-band quarter-wave plate consisting of a half-wave and quarter-wave plate, the one that exhibited relatively flat wavelength dispersion like amorphous polyolefin exhibited almost ideal characteristics.
Ideal circular polarizers can be obtained by combining half-wave and quarter-wave plates.

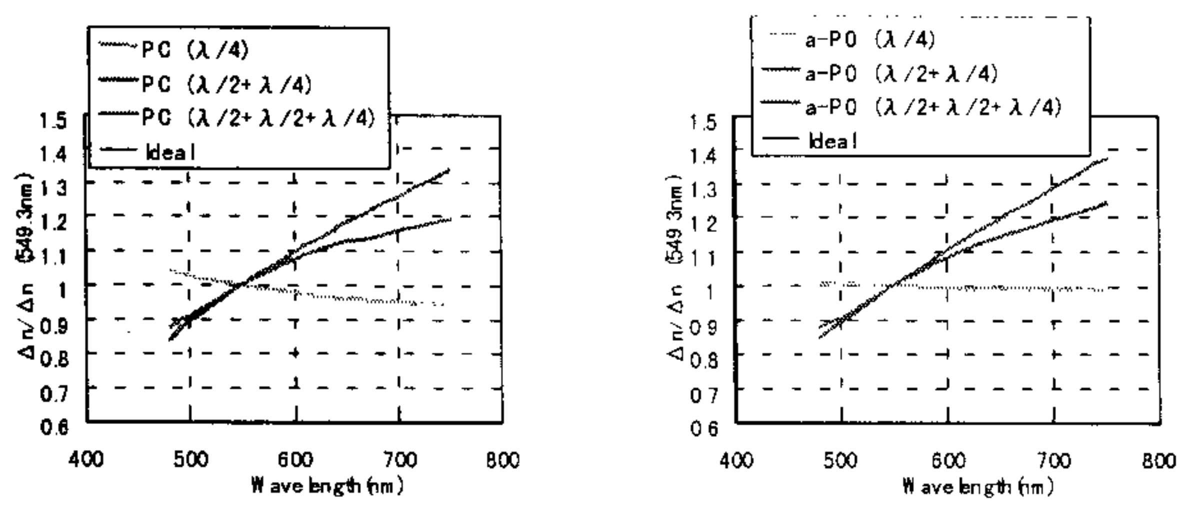

Fig.6 Wavelength dispersion character of wide-band retardation film by combining λ/2 and λ/4.

We have designed wide-band circular polarizers by combining a half-wave and a quarter-wave plate, and have developed commercial products along this line.
In view of cost efficiency, however, we selected wavelength dispersion characteristics of one half-wave and one quarter-wave plate to develop an ideal circular.

2) Wider viewing angle [4) 6)]
To improve on viewing angle of reflective LCDs, both dependency on viewing angle as a polarizing film and as a quarter-wave plate must be eliminated.
Using retardation film for which 3D refractive indices are controlled is an effective way to eliminate dependency on viewing angle of the polarizing films.
In other words, this problem is caused because the polarization axis turns according to viewing angle.
This can be compensated for by using variation in viewing angle of the fast axis of the retardation film.
"NRZ" retardation film for which 3D refractive indices are controlled is suitable for this.
What must be pointed out here is the retardation value of the protective film used for the polarizing films, especially the retardation value in the thickness direction (out of plane) must be taken into account.

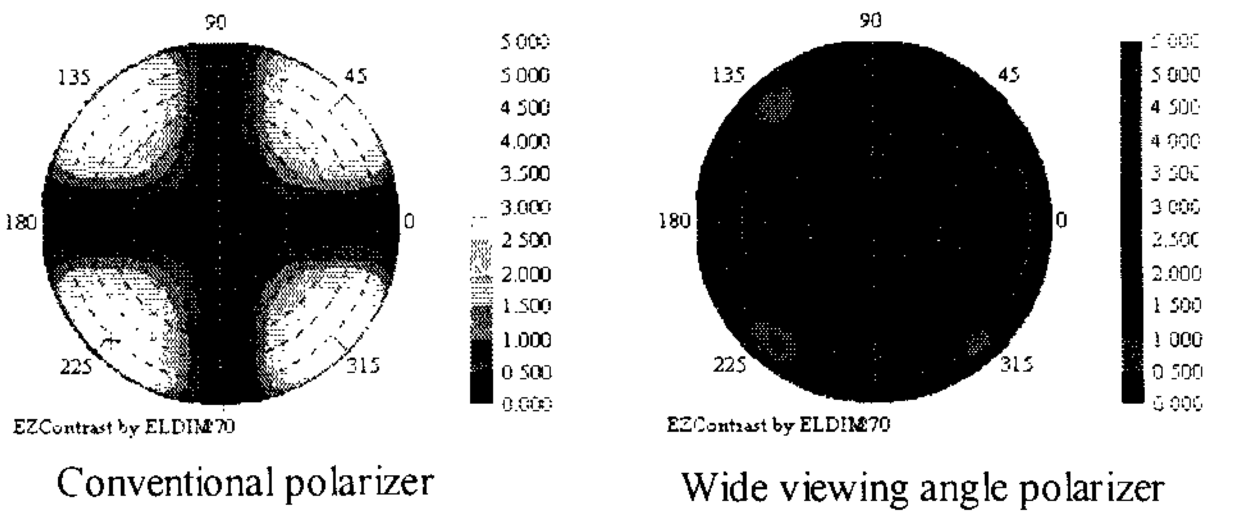

Fig. 7 Viewing angle characteristics of conventional and wide viewing angle polarizers.

As for specific design of wide viewing angle polarizing films, we used materials without birefringence for the protective layer of the polarizing films. As an "NRZ" retardation film, Nz = 0.5 must be satisfied.
Nz = 0.25 and Nz = 0.75 are furthermore combined for the polarizing films that compensates viewing angle for wide band (see Fig. 7). [5) 6)]
Combining half-wave and quarter-wave Nz = 0.5 plates, enables design of a wide-band, wide viewing angle circular polarizer.
Fig. 8 shows the viewing angle characteristics of a wide band circular polarizer consisting of a uniaxial (positive A-plate) half-wave plate and quarter-wave plate combined with a conventional polarizing film, and a wide-band, wide viewing angle circular

polarizer consisting of an "NRZ" half-wave and quarter-wave plate combined with the wide viewing angle polarizing film shown in Fig. 7.
The measurements of Fig. 8 were obtained by measuring shielding characteristics of the circular polarizer on a reflector with an ELDIM EZ-contrast.

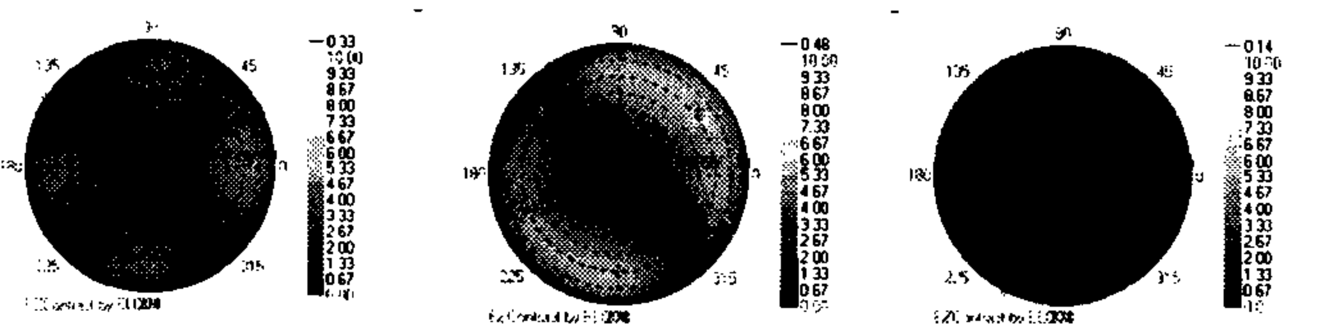

Fig.8 Viewing angle characteristics of conventional and wide viewing angle circular polarizers.

3) Higher reliability

As for the reliability of circular polarizer, there is no wonder that the reliability of polarizing film is important, but that of quarter-wave plate is also essential.
When a quarter-wave plate is subjected to external stress associated with dimensional changes in polarizing films under high temperature and high humidity environments, birefringence is changed by the photoelasticity of the plate, leading to the degradation of circular polarization.
Therefore, polymers with appropriate photoelastic constants need to be selected for use as quarter-wave plates to design high reliability circular polarizer. .
Fig. 9 shows the mapping of transmission for polarizing film applied to both sides of a glass plate to form a crossed Nicol with quarter-wave plate with different photoelastic characteristics between the polarizing films and glass plate and a sample formed so that polarizing axis and fast axis are parallel placed in a high-humidity test chamber set to 60°C, 90% RH for 240 hours.

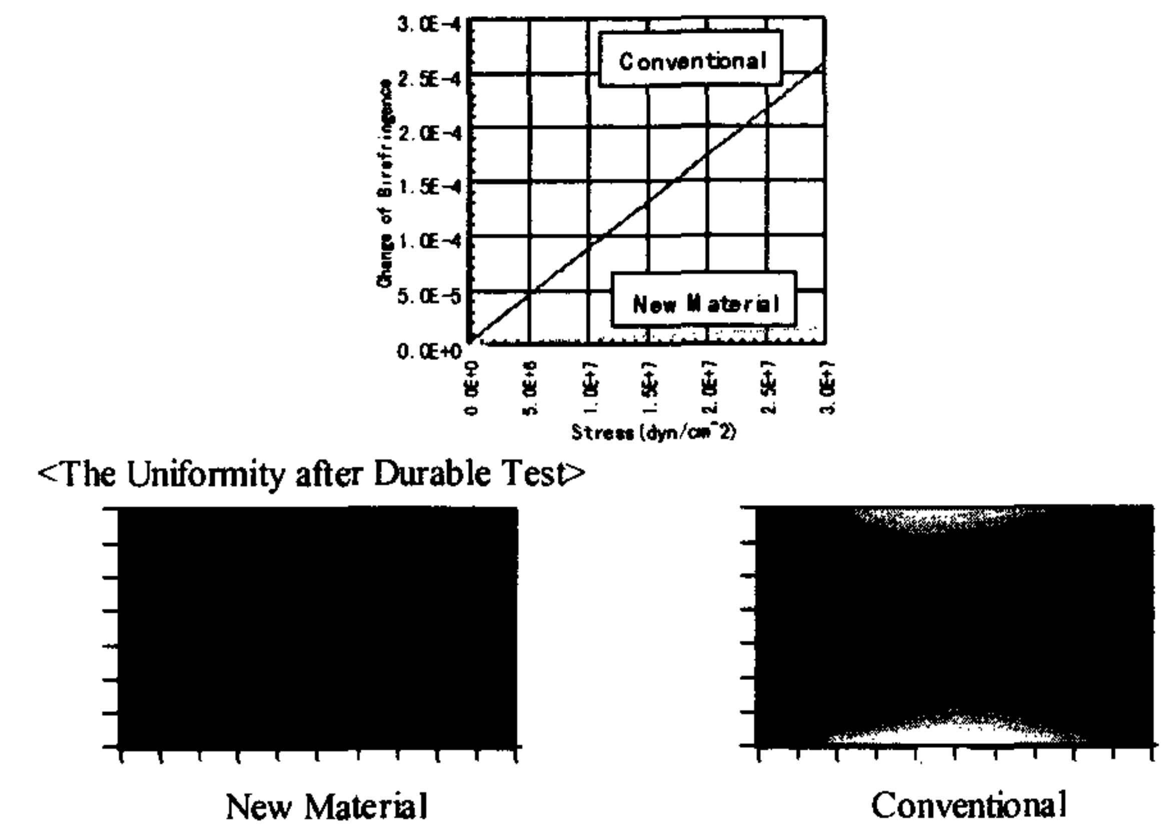

Fig.9 Reliability of quarter wave plate by the photoelasticity.

4) Higher contrast

Optical characteristics of polarizing film, retardation precision and design of quarter-wave plates are important for design of circular polarizers because higher contrast and whiter LCD is required in the market lately. Polarizing films that make up the circular polarizer, surface treatment and interface design are also required.

(1) Surface treatment
In reflective displays, surface reflection relative to shielding rate of polarizing films is large. To what degree surface reflection can be suppressed is connected with higher contrast design. It is particularly important for reflective displays that use ambient-light, unlike transmissive displays.
Anti-reflection effect is achieved with a film that employ interference film are used to prevent surface reflection. This film is generally produced by vacuum process ; so called "dry process", but there is problematic from the standpoint of cost.
Study of reflection prevention using a wet coating process performed under normal pressure is mainstream, some of which realizes approximately 0.5% reflectance (see Fig. 10).

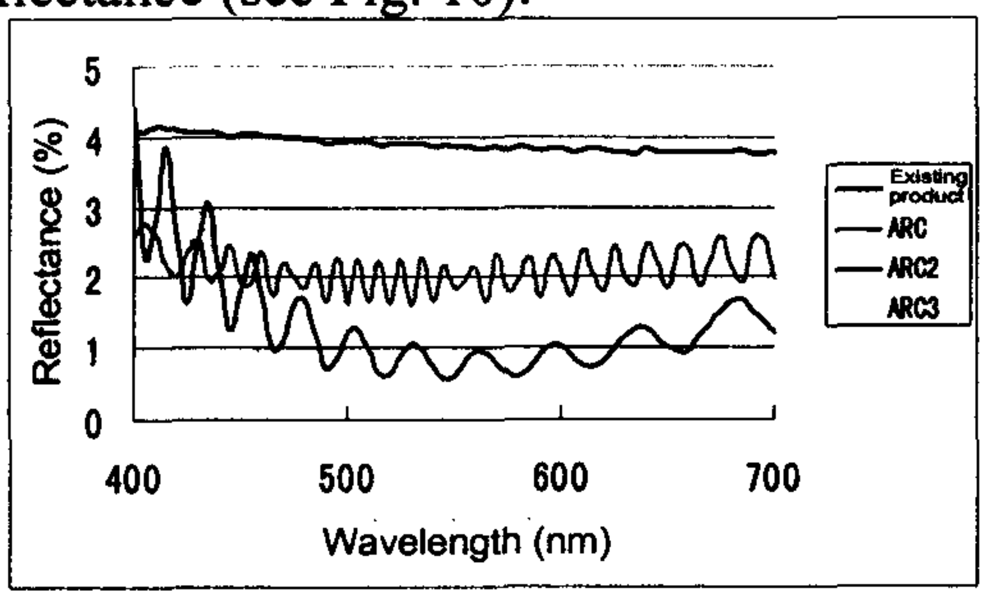

Fig.10 Reflectance of ARC (anti-reflection coat by wet coating) Polarizers.

(2) Interface reflection
Although secondary to surface reflection, reflection at interfaces between stacked polarizing films, half-wave

plates, and quarter-wave plates is significant.
The degradation of contrast due to interface reflection can be suppressed by selecting appropriate refractive indices for film materials and adhesives.
The conventional configuration in Fig. 11 uses a polycarbonate material (n_D=1.59) for retardation film and an acrylic resin adhesive (n_D=1.47). On the other hand, the refractive-index-based configuration in the figure uses an amorphous olefin material (n_D=1.52) for retardation film and a polyester based adhesive (n_D=1.52)

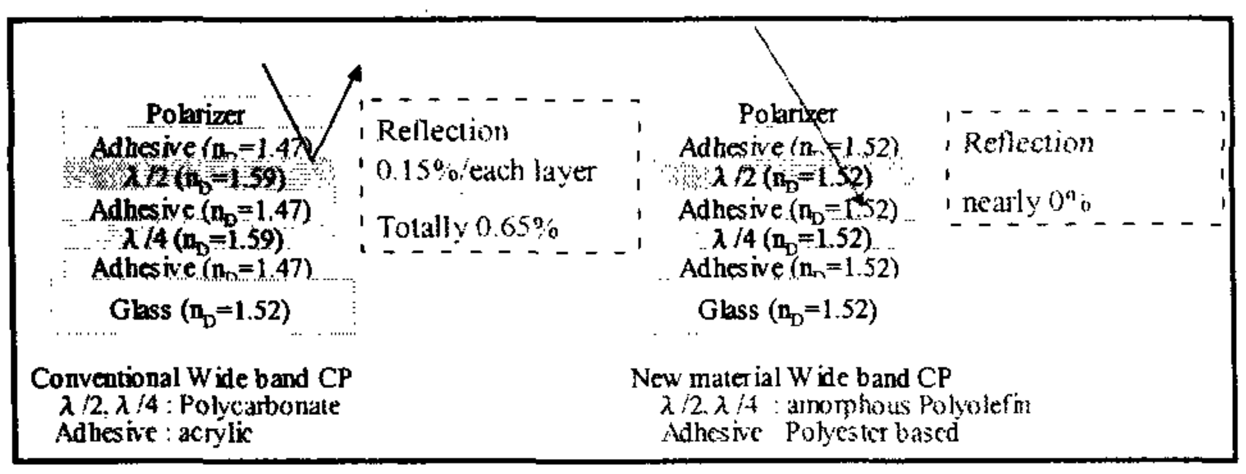

Fig.11 Refractive induces at the interface of circular polarizer.

A higher-contrast reflective LCD can be designed by enhancing performance of the reflection preventative coating and incorporating reduction of reflection at the interface into the design.

4. Conclusions

Key factors in design of optical film that has a large impact on viewing angle and contrast of reflective LCDs include refractive index, retardation value (n [x-y] d, n [x-z] d), wavelength dispersion, and photoelastic constant. Particularly, design of retardation film can not only compensate for birefringence of liquid crystal, but can enhance viewing angle of polarized film from the standpoint of controlling polarized light. By using this technology, you can realize wider viewing angle and wider band for circular polarizers. These wide-band, wide viewing angle circular polarizers are applicable to TN, OCB and VA modes of reflective LCDs. We are very interested in applying them to transmissive and self-illuminating LCDs as well.

5. Acknowledgement

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