Novel Method to Manufacture 1/4-Wave Plate Film Having Nz factor of 0.5 by Solvent for High Performance Devices

Kyosuke Inoue[1], Kazuhiro Osato[1], Kensaku Fujii[1] Takamichi Inomata[1]

[1] Zeon Corporation, Takaoka-shi, Toyama, Japan

Keywords: QWP; ¼-wave plate; COP; Nz factor of 0.5.

ABSTRACT

We introduce a new type ¼-wave plate film (QWP) for high performance devices. This QWP film consists of three layers having Nz factor of 0.5 respectively. Therefore, not only the wavelength dispersion but also the viewing angle are excellent. We also have found the novel way to manufacture films with Nz factor of 0.5 by solvent.

1 Introduction

The spread of mobile devices, represented by smartphones and the tablet PCs, is progressing quickly. Generally, a circular polarizer with QWP is required for OLED displays to obtain good black mode performance. In addition, AR/VR devices have become a hot topic these days. They need high performance display quality to have a sense of immersion. QWP is also used in AR/VR devices for that reason.

In the past study, we had developed two-layer Cyclo Olefin Polymer (hereinafter referred to as COP) film but there is a demand for better optical properties. In 2015, we developed the conventional multi-sheet QWP, and have achieved a QWP combined with an oblique stretched COP film as a λ/2 retarder and an oblique stretched polystyrene (PSt) film as a λ/4 retarder. (We reported in SID in 2015. [1]). In addition, we had developed new type multi-sheet QWP which can be produced using a roll-to-roll, low-cost manufacturing process (We reported in IDW in 2019. [2]). However, there was still room for improvement.

It is known that a three-layer film should be used to achieve the ideal wavelength dispersion.[3] However, it is necessary to control Nz factor to further improve the viewing angle. Therefore, we have developed a three-layer COP film having Nz factor of 0.5 in this study as QWP. When refractive indexes in the plane direction are n_x, n_y, and a refractive index in the film thickness direction is n_z, Re, Rth, and Nz factor are defined as the following equation. d represents the thickness of a film.

$$Re = (n_x - n_y)d \tag{1}$$

$$Rth = \{(n_x + n_y)/2 - n_z\}d \tag{2}$$

$$Nz = (n_x - n_z)/(n_x - n_y) = Rth/Re + 0.5 \tag{3}$$

This QWP has ideal performance in wavelength dispersion and viewing angle. Generally, it is difficult to manufacture the film having Nz factor of 0.5 because it is necessary to orient molecular chains in the thickness direction of the film. However, we have found a novel method to easily manufacture QWP with Nz factor of 0.5 by solvent. It has been found that by contacting film with a solvent in the coating or dipping process, the molecular chains are oriented in the thickness direction. By stretching this film, a film having Nz factor of 0.5 can be easily obtained.

2 Experiment : simulation

We simulated ellipticity of QWP with PVA to evaluate wavelength dispersion and viewing angle. The elliptic characteristics when light was incident at a polar angle 0, 10 and 30 degree were calculated as shown Fig.1.

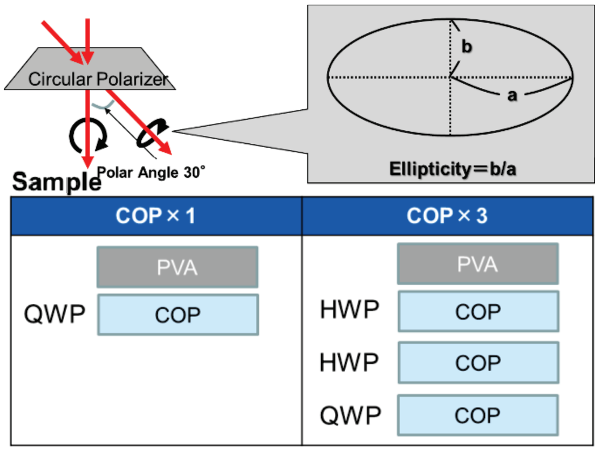


Fig.1 Simulation method

We calculated one-layer COP film and three-layer COP film respectively. The three-layer COP film realizes high-performance QWP by three layers of HWP, HWP, and QWP. Table.1 shows the optical properties used in this simulation.

Table.1 Optical parameters for simulation

one-layer Nz=1.0

	1st
Material	COP
Nz	1.0
Re@590	141nm
θ	45°

three-layer Nz=1.0

	1st	2nd	3rd
Material	COP	COP	COP
Nz	1.0	1.0	1.0
Re@590	274nm	274nm	137nm
θ	6.9°	34.5°	100.4°

three-layer Nz=0.5

	1st	2nd	3rd
Material	COP	COP	COP
Nz	0.5	0.5	0.5
Re@590	274nm	274nm	137nm
θ	6.9°	34.5°	100.4°

3 Results of simulation

The simulation results are shown in Fig.2 and Fig.3. Fig.2 shows the ellipticity spectrum at polar angle 0 degree. Only one-layer and three-layer are shown because they don't depend on Nz factors. It turns out that three-layer is overwhelmingly better.

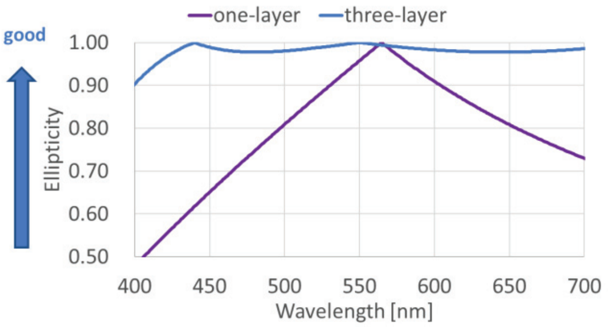


Fig.2 ellipticity spectrum at polar angle 0 degree

Fig.3 shows results of ellipticity at polar angle 10 and 30 degree. They are reported by three typical wavelengths: Red means 650nm, Green means 550nm, and Blue means 450nm. In the one-layer, it can be seen that the ellipticity of Red and Blue is poor even at the polar angle of 10 degree. In the three-layer Nz=1.0, it is excellent at the polar angle of 10 degree but the ellipticity is worse at the polar angle of 30 degree. On the other hand, in three-layer Nz=0.5, it has excellent performance in both wavelength dispersion and polar angle.

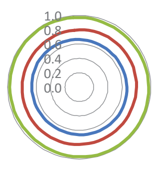
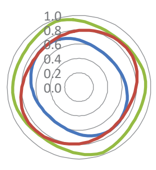
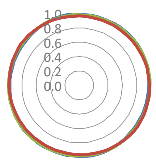
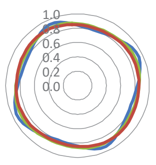
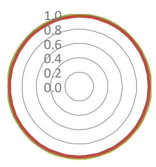
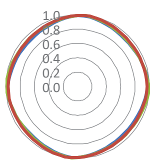
	Polar Angle 10°			Polar Angle 30°		
one-layer Nz=1.0						
	Ave.	Blue	0.66	Ave.	Blue	0.66
		Green	0.97		Green	0.91
		Red	0.80		Red	0.79
three-lyaer Nz=1.0						
	Ave.	Blue	0.98	Ave.	Blue	0.86
		Green	0.98		Green	0.86
		Red	0.97		Red	0.86
three-lyaer Nz=0.5						
	Ave.	Blue	0.99	Ave.	Blue	0.95
		Green	1.00		Green	0.96
		Red	0.98		Red	0.96

Fig.3 Results of simulation

4 Novel method to manufacture

COP is generally amorphous, but it is crystalline COP that is used in this new process. We have succeeded in developing crystalline COP, which has features not found in conventional COP, such as excellent thermal durability and solvent resistance. (We reported in SID in 2017. [4]). We have found another interesting feature from this crystalline COP film. It is the solvent-induced molecular orientation. Fig.4 shows the method to manufacture the crystalline COP film having Nz factor of 0.5. First of all, we prepared isotropic crystalline COP film made by our extrusion process. Next, the film was dipped into toluene and dried. Surprisingly, when we measured the Optical parameters, Re and Rth, the film after dipping in toluene showed positive-C plate. We also evaluated it by WAXD, and the scattering peak suggested that the molecular chains were oriented in the thickness direction of the film. Finally, the film was stretched conventionally. By increasing both Re and Rth, we were able to obtain a film with Nz factor of 0.5.

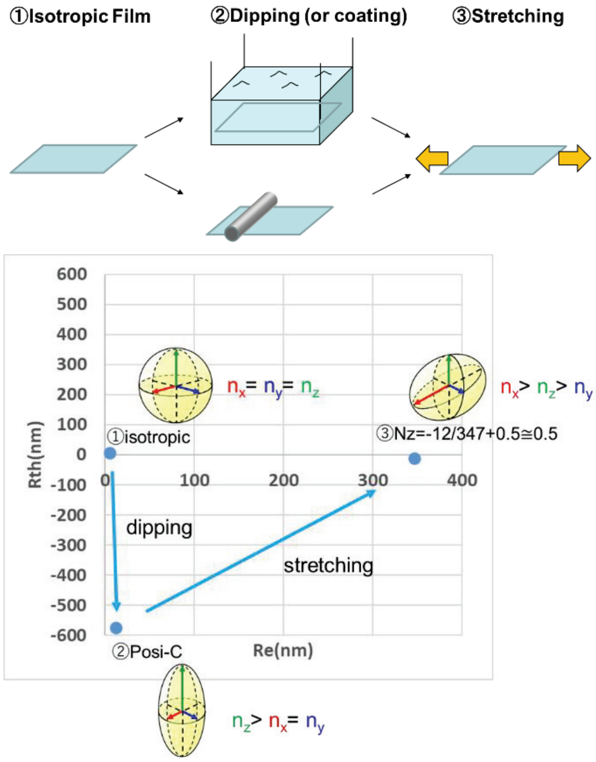


Fig. 4 Method to manufacture film

Furthermore, the thickness of the film after stretching shown in Fig.4 was 45 μm. In other words, QWP can be realized with a thin film of 15 μm. This is because the molecular chains are strongly oriented by toluene. It has been confirmed that this orientation occurs not only with toluene but also with limonene and cyclohexane.

5 Experiment : implementation

First, isotropic crystalline COP film was manufactured by our extrusion process. The film was then dipped into limonene by the process as shown Fig.5. The optical property of the obtained film was Re=56nm, Rth=-438nm.

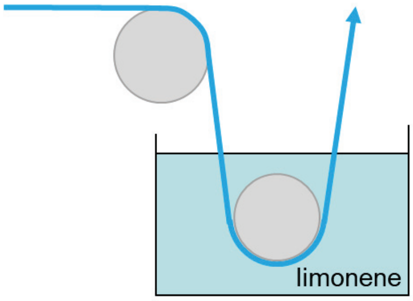


Fig.5 Dipping process

Then, two HWP films were obtained by stretching in slow axis direction, and a QWP film was obtained by stretching in fast axis direction. HWP's optical properties were respectively, Re=280nm, Rth=-11, Nz=0.46 and Re=280nm, Rth=-14nm, Nz=0.45. QWP's optical property was Re=140nm, Rth=-11nm, Nz=0.42. The measurement wavelength was 590nm.

6 Results of implementation

The three-layer structures were laminated at the target angles using adhesives. The optical properties of the films used for evaluation are shown in Table.2.

Table.2 Optical parameters for implement

one-layer Nz=1.0

	1st
Material	COP
Nz	1.0
Re@590	140nm
θ	45°

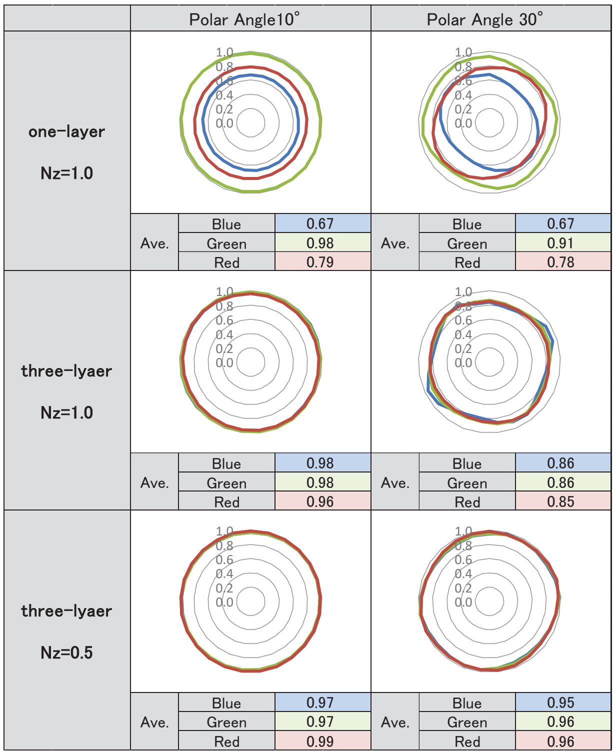
three-layer Nz=1.0

	1st	2nd	3rd
Material	COP	COP	COP
Nz	1.0	1.0	1.0
Re@590	280nm	280nm	140nm
θ	6.9°	34.5°	100.4°

three-layer Nz=0.5

	1st	2nd	3rd
Material	COP	COP	COP
Nz	0.46	0.45	0.42
Re@590	280nm	280nm	140nm
θ	6.9°	34.5°	100.4°

In order to evaluate films, these were laminated with polarizes using adhesives, and the ellipticities at 450nm, 550nm, and 650nm were measured in the same as the simulation. These results are shown in Fig.6. results similar to the simulation were obtained, and it was shown that the three-layer structure having Nz factor of 0.5 is the best.



		Polar Angle10°		Polar Angle 30°
one−layer Nz=1.0	Ave. Blue	0.67	Ave. Blue	0.67
	Green	0.98	Green	0.91
	Red	0.79	Red	0.78
three−lyaer Nz=1.0	Ave. Blue	0.98	Ave. Blue	0.86
	Green	0.98	Green	0.86
	Red	0.96	Red	0.85
three−lyaer Nz=0.5	Ave. Blue	0.97	Ave. Blue	0.95
	Green	0.97	Green	0.96
	Red	0.99	Red	0.96

Fig.6 Results of implement

7 Conclusions

We have found a unique process of QWP having Nz factor of 0.5. If we can realize the production of this film, films with excellent wavelength dispersion and viewing angle characteristics can be made thinner, which can contribute to improving display quality.

References

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