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TITLE OF INVENTION

METHOD AND APPARATUS FOR MEASURING THICKNESS OF BIREFRINGENCE LAYER

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a method and apparatus for measuring a thickness of a birefringence layer of an object to be measured such as liquid crystal.

Description of the Prior Art

In a prior art apparatus for measuring a thickness of a liquid crystal layer, a liquid crystal cell to be measured is placed between a polarizer and an analyzer. A light source generates a light having a plurality of wavelengths, and a monochrometer or a spectrometer receives the light and generates a light having a single wavelength λ . The light is passed through the polarizer, the liquid crystal layer and the analyzer successively, and the light transmitting the analyzer is detected by a photosensor. The direction of transmission axis of the polarizer is parallel to the rubbing direction of the incident side of the liquid crystal cell. The liquid crystal to be measured has a liquid crystal twist angle of about 90° .

A thickness of a liquid crystal layer is measured with the apparatus described above. If the wavelength of a

light emitted by the monochromatic meter is represented as λ , the transmittance T of the light transmitting the polarizer, the liquid crystal and the analyzer is expressed as follows:

$$T = \sin^2((\pi/2)\sqrt{1+u^2}) / (1+u^2), \quad (1)$$

where

$$u = 2\Delta n d / \lambda,$$

Δn denotes a degree of birefringence of liquid crystal or a difference between a normal index of refraction and an abnormal index of refraction, and d denotes a thickness of the liquid crystal layer. Then, Eq. (2) is derived from Eq. (1) if the wavelength at which the transmittance T becomes zero is denoted as λ_s .

$$d = \lambda_s / \Delta n \sqrt{m^2 - 1/4}, \quad (2)$$

where

$$m = 1, 2, 3, \dots$$

Thus, the wavelength at which the optical intensity detected by the photosensor becomes zero, or the wavelength λ_s at which the transmittance T becomes zero is determined by changing the wavelength of the monochromatic meter. Then, the wavelength λ_s is substituted in Eq. (2), the thickness d of the liquid crystal layer is determined.



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However, the method explained above has several disadvantages. First, a liquid crystal layer on which the thickness can be measured is limited to a layer having a twist angle of about 90° . Further, it is needed to make the rubbing direction of the liquid crystal cell to the transmission direction of the two polarizers, the rubbing direction has to be known. However, it is usually difficult to measure the rubbing direction, and it is impossible to set the rubbing direction of the liquid crystal correctly to agree with the transmission direction of the two polarizers. Further, because the monochromatic meter or a spectrometer is needed, a time of about one minute is needed for measurement. Therefore, it cannot be applied to uses such as in-line inspection that need a high speed processing. Finally, because the monochromatic meter or a spectrometer is used, the apparatus has a complicated structure, and its cost is high.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a method and an apparatus for measuring a thickness of a birefringence layer correctly and at a high speed enough for in-line inspection, even for a liquid crystal that does not have a twist angle of 90° or on which rubbing direction is not known, and can be fabricated at a low cost.

In one aspect of the invention, a thickness of a birefringence layer is measured as follows: An object to be



measured having a birefringence layer such as a liquid crystal cell and a phase plate are provided in an optical path of a light between first and second polarizers in parallel Nicol or in crossed Nicol arrangement. The phase plate is set so that a direction of transmission of the first polarizer agrees with an optical axis of the light. Then, the phase plate is rotated while detecting an optical intensity of light transmitting the second polarizer. Thus, a rotation angle of the phase plate is determined at which the optical intensity has an extreme value. Then, a thickness of the birefringence layer is calculated according to the rotation angle at the extreme value.

In a second aspect of the invention, a thickness of a birefringence layer having an orientation direction such as a liquid crystal having rubbing direction is measured in a different way as follows: In this method, a $\lambda/2$ plate (half-wave plate) is used as the phase plate, and the object to be measured having a birefringence layer is set so as to be rotated. First, the object is rotated, and it is set at a position so that an optical intensity of light transmitting the second polarizer has an extreme value. Next, the $\lambda/2$ plate is rotated, and a rotation angle of the $\lambda/2$ plate is determined at which an optical intensity of light transmitting the second polarizer has an extreme value. Then, a thickness



of the birefringence layer is calculated according to the rotation angle of the $\lambda/2$ plate.

An advantage of the present invention is that the thickness is measured at a high speed.

Another advantage of the present invention is that a liquid crystal cell having a twist angle other than 90° can be measured.

A further advantage of the present invention is that the thickness can be measured with a very simple optical system.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become clear from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings, and in which:

Fig. 1 is a diagram of a basic optical system for a method for measuring a thickness of birefringence layer of a first embodiment of the invention;

Fig. 2 is a diagram of a flow of the measuring method of the first embodiment;

Fig. 3 is a diagram for explaining coordinates in the optical system of the embodiment;

Fig. 4 is a graph of detected intensity plotted against angle of rotation of a phase plate in a case of the

polarizers in parallel Nicol and the phase differences δ of the phase plate 4 of $\lambda/8$ where λ is a wavelength;

Fig. 5 is a graph of detected intensity plotted against angle of rotation of a phase plate in a case of the polarizers in crossed Nicol and the phase differences δ of the phase plate 4 of $\lambda/8$;

Fig. 6 is a graph of detected intensity plotted against angle of rotation of a phase plate in a case of the polarizers in parallel Nicol and the phase differences δ of the phase plate 4 of $\lambda/4$;

Fig. 7 is a graph of detected intensity plotted against angle of rotation of a phase plate in a case of the polarizers in crossed Nicol and the phase differences δ of the phase plate 4 of $\lambda/4$;

Fig. 8 is a graph of detected intensity plotted against angle of rotation of a phase plate in a case of the polarizers in parallel Nicol and the phase differences δ of the phase plate 4 of $\lambda/2$;

Fig. 9 is a graph of detected intensity plotted against angle of rotation of a phase plate in a case of the polarizers in crossed Nicol and the phase differences δ of the phase plate 4 of $\lambda/2$;

Fig. 10 is a diagram of an apparatus for measuring a thickness of birefringence layer;

Fig. 11 is a diagram of another basic optical system for measuring a thickness of birefringence layer of a second embodiment of the invention;

Fig. 12 is a diagram of a flow of the measuring method of the second embodiment; and

Fig. 13 is a diagram of another apparatus for measuring a thickness of birefringence layer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, wherein like reference characters designate like or corresponding parts throughout the several views, Fig. 1 shows a basic optical system for measuring a thickness of a birefringence layer of a first embodiment of the invention. In Fig. 1, a single wavelength light source 1 such as a laser device emits a light of a wavelength λ . Along the optical axis 10 of the light, a polarizer 2, a liquid crystal layer 3 contained in a liquid crystal cell, a phase plate 4, another polarizer 6 and a photosensor 7 are arranged successively. The liquid crystal layer 3 is an example of an object to be measured having a birefringence layer, and it has ordinary index n_o and extraordinary index n_e . The object 3 is provided between the two polarizers 2 and 6 that are set in parallel Nicol or in crossed Nicol arrangement. The phase plate 4 having a phase difference δ is provided between the two polarizers 2, 6.

Thus, the photosensor 7 detects a light transmitting the second polarizer 6.

Next, it is explained with reference to a flowchart of Fig. 2 how a thickness of the birefringence layer 3 is measured with use of the optical system having the above-mentioned structure. First, the first polarizer 2 and the second one 6 are set in parallel Nicol or crossed Nicol arrangement with a liquid crystal layer 3 interposed between them (step S2). Next, the optical axis of the phase plate 4 is set to agree with the transmission axis of the first polarizer 2 (step S4). Then, the phase plate 4 is rotated, and a rotation angle α at which the detection intensity of the photosensor 7 has an extreme value is measured (step S6). Then, the rotation angle α measured is substituted into Eq. (11) explained later, and the thickness of the birefringence layer (liquid crystal layer) 3 is calculated (step S8).

Next, a principle of the above-mentioned method for measuring the thickness of a birefringence layer (liquid crystal layer) is explained with reference to numerical formulas.

Fig. 3 shows coordinates of the optical system shown in Fig. 1. In Fig. 3, reference numeral 10 denotes the transmission axis of the polarizer 2, and an angle relative to x axis is denoted as e_t . Reference numeral 11 denotes a rubbing direction at the incoming side of the liquid crystal

3, and an angle relative to x axis is taken as ϕ . Reference numeral 12 denotes the rubbing direction of the liquid crystal cell at the outgoing side, and a twist angle defined as an angle between the rubbing directions at the incoming side of the cell and at the outgoing side is taken as θ . The rubbing direction represents a direction of the liquid crystal orientation in the liquid crystal cell. Reference numeral 13 denotes the optical axis of the phase plate 4, and an angle relative to x axis is taken as α . Reference numeral 14 denotes the transmission axis of the polarizer 6, and an angle relative to x axis is taken as e_x .

By using the coordinates stated above, a light transmitting through the polarizer 2 is written in Eq. (3) by using Jones vector A.

$$A = \begin{pmatrix} \cos(e_t) \\ \sin(e_t) \end{pmatrix}.$$

(3)

Further, Jones matrix B of the liquid crystal 3 is written in Eq. (4), Jones matrix C of the phase plate 4 is written in Eq. (5), and Jones matrix D of the other polarizer 6 is written in Eq. (6).

$$B = \exp(-i\eta) \begin{pmatrix} p+qi & r+si \\ -r+si & p-qi \end{pmatrix},$$

(4)

where

$$p = \cos(\gamma) \cos(\theta) + (\theta/\gamma) \sin(\gamma) \sin(\theta),$$

$$q = -(\beta/\gamma) \sin(\gamma) \cos(\theta + 2\phi),$$

$$r = -\cos(\gamma) \sin(\theta) + (\theta/\gamma) \sin(\gamma) \cos(\theta),$$

$$s = -(\beta/\gamma) \sin(\gamma) \sin(\theta + 2\phi),$$

$$\gamma = \sqrt{\beta^2 + \theta^2},$$

$$\eta = d(n_e + n_o) \pi / \lambda,$$

and

$$\beta = d(n_e - n_o) \pi / \lambda.$$

$$C=R(\alpha)\begin{pmatrix}\exp(i\delta/2) & 0 \\ 0 & \exp(-i\delta/2)\end{pmatrix}, \quad (5)$$

where

$$R(\theta)=\begin{pmatrix}\cos\theta & -\sin\theta \\ \sin\theta & \cos\theta\end{pmatrix}.$$

$$D=R(e_x)\begin{pmatrix}1 & 0 \\ 0 & 0\end{pmatrix}R(-e_x). \quad (6)$$

Therefore, Jones vector $E(E_x, E_y)$ of a light transmitting the polarizer 6 is written in Eq. (7), and the intensity F detected by the photosensor 7 is written in Eq. (8).

$$E=\begin{pmatrix}E_x \\ E_y\end{pmatrix}=DCBA. \quad (7)$$

$$F=|E_x|^2+|E_y|^2. \quad (8)$$

Generality is not lost if the direction of the transmission axis of the polarizer 2 is taken as $e_t = 0$. Then, e_t is set as zero. Then, the direction of the transmis-

sion axis e_x of the other polarizer 6 is set to have $e_x = 0^\circ$ for parallel Nicol or 90° for crossed Nicol.

In case of parallel Nicol, the intensity F_1 detected by the photosensor 7 is written as Eq. (9), and in case of crossed Nicol, the intensity F_2 detected by the photosensor 7 is written as Eq. (10).

$$\begin{aligned}
 F_1 &= F_{et=0, ex=0} \\
 &= \frac{1}{4} \{ (-p^2 - q^2 + r^2 + s^2) \cos(\delta) + p^2 + q^2 - r^2 - s^2 \} \cos(4\alpha) \\
 &+ \frac{1}{2} \{ (pr - sq) \cos(\delta) - pr + sq \} \sin(4\alpha) - (ps + qr) \sin(\delta) \sin(2\alpha) \\
 &+ \frac{1}{4} \{ p^2 + q^2 - r^2 - s^2 \} \cos(\delta) + \frac{3}{4} (p^2 + q^2) + \frac{1}{4} (r^2 + s^2) .
 \end{aligned}
 \tag{9}$$

$$\begin{aligned}
 F_2 &= F_{et=0, ex=\frac{\pi}{2}} \\
 &= \frac{1}{4} \{ (p^2 + q^2 - r^2 - s^2) \cos(\delta) - p^2 - q^2 + r^2 + s^2 \} \cos(4\alpha) \\
 &+ \frac{1}{2} \{ (-pr + sq) \cos(\delta) + pr - sq \} \sin(4\alpha) + (qr + ps) \sin(\delta) \sin(2\alpha) \\
 &+ \frac{1}{4} \{ -p^2 - q^2 + r^2 + s^2 \} \cos(\delta) + \frac{1}{4} (p^2 + q^2) + \frac{3}{4} (r^2 + s^2) .
 \end{aligned}
 \tag{10}$$

Next, simulation of the detection intensities F_1 and F_2 is performed with simulation conditions compiled in Table 1.

Table 1

Degree of birefringence of liquid crystal ($\Delta n = n_e - n_o$)	0.1
Twist angle of liquid crystal (θ)	88°
Rubbing direction of liquid crystal (ϕ)	46°
Thickness of liquid crystal layer (d: μm)	5.0
Measurement wavelength (λ : nm)	633

Figs. 4 - 9 show relations of the intensity detected with the photosensor 7 for parallel Nicol or for crossed Nicol to the rotation angle α of the phase plate 4. Table 2 shows a relation of the polarization state of the phase difference of the phase plate 4 and the polarizers 2 and 6 to the number of the drawings. In other words, Fig. 4 shows a case of the polarizers in parallel Nicol and the phase differences δ of the phase plate 4 of $\lambda/8$; Fig. 5 shows a case of the polarizers in crossed Nicol and the phase differences δ of the phase plate 4 of $\lambda/8$; Fig. 6 shows a case of the polarizers in parallel Nicol and the phase differences δ of the phase plate 4 of $\lambda/4$; Fig. 7 shows a case of the polarizers in crossed Nicol and the phase differences δ of the phase plate 4 of $\lambda/4$; Fig. 8 shows a case of the polarizers in parallel Nicol and the phase differences δ of the phase plate 4 of $\lambda/2$; and Fig. 9 shows a case of the polarizers in crossed Nicol and the phase differences δ of the phase plate 4 of $\lambda/2$.

Table 2

Number of drawing	Phase difference δ	Polarization condition
4	$\lambda/8$	Parallel Nicol
5	$\lambda/8$	Crossed Nicol
6	$\lambda/4$	Parallel Nicol
7	$\lambda/4$	Crossed Nicol
8	$\lambda/2$	Parallel Nicol
9	$\lambda/2$	Crossed Nicol

As will be understood from Figs. 4 - 9, the optical intensity detected by the photosensor 7 has an extreme value irrespective of phase difference of the phase plate 4 and the polarization state. The rotation angle α of the phase plate 4 at an extreme value can be determined by differentiating Eqs. (9) and (10) with α , as shown in Eqs. (11) and (12).

$$\frac{\partial F_1}{\partial \alpha} = 0.$$

$$\begin{aligned} \therefore \{ (p^2 + q^2 - r^2 - s^2) \cos(\delta) - p^2 - q^2 + r^2 + s^2 \} \sin(4\alpha) \\ + 2 \{ (pr - sq) \cos(\delta) - pr + sq \} \cos(4\alpha) \\ - 2 (ps + qr) \sin(\delta) \cos(2\alpha) = 0. \end{aligned}$$

(11)

$$\frac{\partial F_2}{\partial \alpha} = 0.$$

$$\begin{aligned} \therefore \{ (p^2 + q^2 - r^2 - s^2) \cos(\delta) - p^2 - q^2 + r^2 + s^2 \} \sin(4\alpha) \\ + 2 \{ (pr - sq) \cos(\delta) - pr + sq \} \cos(4\alpha) \\ - 2 (ps + qr) \sin(\delta) \cos(2\alpha) = 0. \end{aligned}$$

(12)

By observing the two equations, it is found that Eq. (11) is the same as Eq. (12).

If difference in ordinary and extraordinary indices of liquid crystal ($\Delta n = n_e - n_o$), twist angle of liquid crystal (θ), rubbing direction of liquid crystal (ϕ), the measurement wavelength (λ), the phase difference (δ) of the phase plate and the rotation angle α of the phase plate at an extreme value are known in Eq. (11), only the thickness d of liquid crystal layer is not known. Then, the thickness d can be determined by solving Eq. (11).

The precision of the measurement of the thickness of the liquid crystal layer is determined by the measurement precision of the rotation angle α of the phase plate 3. Precision of thickness of 10 nm can be obtained with precision of rotation angle of 0.05° . The measurement is completed in a time where the phase plate 4 is rotated by several degrees or in about one second. Thus, it is an advantage that the measurement is performed at a high speed.

As described above, according to the present embodiment, the intensity detected by the photosensor 7 is

changed by rotating the phase plate 4. Then, a rotation angle α at which the intensity has an extreme value is measured, and the thickness d of the liquid crystal layer is determined at a high precision according to Eq. (11).

Fig. 10 shows an apparatus for measuring a thickness of a birefringence layer. In Fig. 10, like reference characters denote substantially the same components shown in Fig. 1. A rotating means 5 rotates the phase plate 4. A controller 8 controls the rotating means 5 on the basis of signals of the photosensor 7, and a computer 9 calculated the thickness d of the liquid crystal 3 as an object to be measured according to the rotation angle of the phase plate 4 with the controller 8.

A method of measuring a thickness of a birefringence layer in the optical system having the above-mentioned structure is explained with reference to the flowchart of Fig. 2. The birefringence layer such as a liquid crystal cell has an orientation direction at an incidence side thereof. First, the polarizers 2 and 6 are set in parallel Nicol or crossed Nicol arrangement with a liquid crystal cell 3 set on the rotating means 5 between them. Next, the optical axis of the phase plate 4 is set to agree with the transmission axis of the polarizer 2. Then, the phase plate 4 is rotated by the controller 8 and the rotating means 5, and a rotation angle α at which the detection intensity of the photosensor 7 has

an extreme value is measured. Then, the rotation angle α is substituted into Eq. (11), and the thickness of the birefringence layer (liquid crystal layer 3) is calculated with the computer 9. Thus, the thickness of the birefringence layer (liquid crystal layer 4) is calculated.

The present embodiment has several advantages. Because the thickness can be measured with a very simple optical system, a measurement apparatus can be provided at a low cost. Further, because the measurement can be performed at a high speed, the number of samples can be increased from sample test to total inspection. Thus, a yield in a fabrication process that uses this apparatus may be increased. Still further, because samples of the twist angle of liquid crystal other than 90° can be measured in contrast to prior art, various liquid crystals can be measured.

Though a simple phase plate 4 is used in the embodiment, it is needless to say that a Babinet Soleil compensator having a combination of phase plates may also be used.

In the embodiment, a liquid crystal layer is an object to be measured. However, the object is not limited to liquid crystal, and a thickness of any object having birefringence can be measured.

Next, a second embodiment of the invention is explained for measuring a thickness of a birefringence layer. Fig. 11 shows a basic optical system of the second embodiment

wherein like reference characters denote substantially the same components shown in Fig. 1.

Next, it is explained with reference to a flowchart shown in Fig. 12 how a thickness of a birefringence layer such as a liquid crystal layer is measured in the above-mentioned optical system. First, the polarizers 2 and 6 are set in parallel Nicol or crossed Nicol arrangement (step S10). Then, the liquid crystal 3 is rotated, and it is set at a position where the detection intensity of the photosensor 7 has an extreme value (step S12). Next, the optical axis of the $\lambda/2$ plate (half-wave plate) 16 is set to agree with the transmission axis of the polarizer 2 (step S14). Then, the $\lambda/2$ plate 16 is rotated, and a rotation angle α at which the detection intensity of the photosensor 7 has an extreme value is measured (step S16). Then, the rotation angle α is substituted into Eq. (18) explained later, and the thickness of the birefringence layer (liquid crystal layer) is calculated (step S18).

Next, a principle of the measuring method is explained with reference to numerical formula, and it is shown that the thickness of a liquid crystal layer can be measured even if the rubbing direction ϕ of liquid crystal is not known.

When the $\lambda/2$ plate 16 is not used, Jones vector $G(G_x, G_y)$ of a light transmitting the polarizer 6 is written

in Eq. (13), and an intensity H detected by the photosensor 7 is written in Eq. (14).

$$G = \begin{pmatrix} G_x \\ G_y \end{pmatrix} = DBA. \quad (13)$$

$$H = |G_x|^2 + |G_y|^2. \quad (14)$$

Generality is not lost if the direction of the transmission axis e_x of the polarizer 2 is taken as $e_t = 0$, as in the first embodiment. Then, e_t is set at zero. Then, the direction of the transmission axis e_x of the other polarizer 6 is taken at 0° for parallel Nicol or at 90° for crossed Nicol.

In case of parallel Nicol, the intensity H_1 detected by the photosensor 7 is written in Eq. (15), and in case of crossed Nicol, the intensity H_2 detected by the photosensor 7 is written in Eq. (16).

$$\begin{aligned}
 H_1 &= H_{et=0, ex=0} \\
 &= p^2 + q^2 \\
 &= \cos^2(\gamma) \cos^2(\theta) + \frac{\theta}{2\gamma} \sin(2\gamma) \sin(2\theta) \\
 &\quad + \frac{\theta^2}{\gamma^2} \sin^2(\gamma) \sin^2(\theta) + \frac{\beta^2}{\gamma^2} \sin^2(\gamma) \cos^2(\theta + 2\phi) .
 \end{aligned}
 \tag{15}$$

$$\begin{aligned}
 H_2 &= H_{et=0, ex=\frac{\pi}{2}} \\
 &= r^2 + s^2 \\
 &= \cos^2(\gamma) \sin^2(\theta) - \frac{\theta}{2\gamma} \sin(2\gamma) \sin(2\theta) \\
 &\quad + \frac{\theta^2}{\gamma^2} \sin^2(\gamma) \cos^2(\theta) + \frac{\beta^2}{\gamma^2} \sin^2(\gamma) \sin^2(\theta + 2\phi) .
 \end{aligned}
 \tag{16}$$

It can be understood from Eqs. (15) and (16), the fourth terms in Eqs. (15) and (16) change as the liquid crystal layer 3 is rotated, and the detection intensity is changed.

The value at an extreme value of the detection intensity is determined as ϕ where partial differentials of Eqs. (15) and (16) with ϕ become zero, and it is shown in Eq. (17).

$$\phi = (m\pi - 2\theta) / 4,
 \tag{17}$$

wherein m is an integer.

By using Eq. (17), elements q and s of a Jones matrix of the liquid crystal layer related to the rubbing

direction ϕ of the liquid crystal cell has values shown in Table 3, and they are not relevant to the rubbing direction ϕ of the liquid crystal cell.

Table 3

Polarization state	Extreme values	q	s
Parallel Nicol	Maximum	$\pm(\beta/\gamma)\sin(\gamma)$	0
Parallel Nicol	Minimum	0	$\pm(\beta/\gamma)\sin(\gamma)$
Crossed Nicol	Maximum	0	$\pm(\beta/\gamma)\sin(\gamma)$
Crossed Nicol	Minimum	$\pm(\beta/\gamma)\sin(\gamma)$	0

When these values are substituted in Eq. (11), signs of $\pm$ are deleted in the first and second terms in the left hand side because they are terms of q^2 , s^2 or qs . On the other hand, because a sign of $\pm$ remains in the third term of $(ps + qr)$, the thickness of the liquid crystal layer cannot be determined uniquely. However, because the $\lambda/2$ plate 16 is used, $\sin \delta = \sin \pi = 0$ in the third term in Eq. (11). Thus, there exist no term depending on the sign $\pm$. Thus, the thickness of liquid crystal layer can be determined uniquely.

By substituting π in the phase difference δ in Eq. (11) and by using Table 3, Eq. (18) is obtained.

$$\tan(4\alpha) = \frac{2pr}{r^2 + s^2 - p^2 - q^2}.$$

(18)

If difference between extraordinary and ordinary indices of liquid crystal ($\Delta n = n_e - n_o$), twist angle of liquid crystal (θ), the measurement wavelength (λ) and the rotation angle α of the phase plate at an extreme value are known in Eq. (18), only the thickness d of the liquid crystal layer is not known. Then, the thickness d can be determined by solving Eq. (18).

Fig. 13 shows an apparatus for measuring a thickness of birefringence layer wherein like reference numbers represent like components having the same function. A rotating means 15 rotates the liquid crystal layer 3. A controller 17 controls the rotation of the rotation means 15 for the liquid crystal layer 3 and the rotating means 5 for the phase plate 16. A computer 18 calculates the thickness d of the liquid crystal 3 as an object to be measured according to the rotation angle of the $\lambda/2$ plate 16 obtained with the controller 17.

A method of measuring a thickness of a birefringence layer in the optical system in the apparatus is explained with reference to the flowchart of Fig. 12. First, the polarizers 2 and 6 are set in parallel Nicol or crossed Nicol. Next, the liquid crystal layer 3 is set on the rotating means 15

therefor, and it is rotated by the rotating means 15 controlled by the controller 17. Thus, it is set at a position at which the detection intensity of the photosensor 7 has an extreme value. Next, the optical axis of the $\lambda/2$ plate 16 is set to agree with the transmission axis of the polarizer 2. Then, the $\lambda/2$ plate 16 is rotated by the rotating means 5 means 17 controlled by the rotation means 17, and a rotation angle α at which the detection intensity of the photosensor 7 has an extreme value is measured. Then, the rotation angle α is substituted into Eq. (18) as explained above, and the thickness of the liquid crystal layer is calculated with the computer 18.

As described above, advantages similar to those in the first embodiment are realized. Further, by rotating the liquid crystal layer 3 to set it at an extreme value, the thickness of the liquid crystal layer (birefringence layer) is determined correctly according to the rotation angle of the $\lambda/2$ plate even if the rubbing direction of the liquid crystal is not known.

Although the present invention has been fully described in connection with the preferred embodiments thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art. Such changes and modifications are to be understood as included within the scope of the present

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invention as defined by the appended claims unless they depart therefrom.



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WHAT IS CLAIMED IS:

1. A method for measuring a thickness of a birefringence layer comprising the steps of:

(a) providing an object to be measured having a birefringence layer in an optical path of a light between first and second polarizers in parallel Nicol or in crossed Nicol;

(b) providing a phase plate between the first and second polarizers so that a direction of transmission of the first polarizer agrees with an optical axis of the light;

(c) rotating the phase plate, and measuring a rotation angle of the phase plate at which an optical intensity of light transmitting the second polarizer has an extreme value; and

(d) calculating a thickness of the birefringence layer according to the rotation angle of the phase plate.

2. The method according to Claim 1, wherein said phase plate comprises a Babinet-Soleil compensator.

3. The method according to Claim 1, wherein said birefringence layer comprises a liquid crystal layer.

4. An apparatus for measuring a thickness of a birefringence layer comprising:

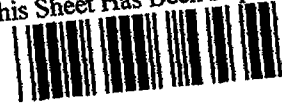
a light source emitting a light having a single wavelength;

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first and second polarizers set in parallel Nicol or in crossed Nicol in an optical path of the light;

an object to be measured having a birefringence layer and provided between said first and second polarizers;

a phase plate provided between said first and second polarizers; and

a photosensor for detecting a light transmitting the second polarizer.

5. The apparatus according to Claim 4, further comprising a means for rotating said phase plate.

6. The apparatus according to Claim 4, wherein said phase plate comprises a Babinet-Soleil compensator.

7. The apparatus according to Claim 4, wherein said birefringence layer comprises a liquid crystal layer.

8. A method for measuring a thickness of a birefringence layer, the birefringence layer having an orientation direction at an incidence side thereof, the method comprising the steps of:

(a) providing an object to be measured having a birefringence layer in an optical path of a light between first and second polarizers in parallel Nicol or in crossed Nicol;

(b) rotating the object, and setting a position of the birefringence layer so that an optical intensity transmitting the second polarizer has an extreme value;



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(c) providing a $\lambda/2$ plate between the first and second polarizers so that a direction of transmission of the first polarizer agrees with an optical axis of the light;

(d) rotating the $\lambda/2$ plate, and measuring a rotation angle of the $\lambda/2$ plate at which an optical intensity transmitting the second polarizer has an extreme value; and

(e) calculating a thickness of the birefringence layer according to the rotation angle of the $\lambda/2$ plate.

9. The method according to Claim 8, wherein said birefringence layer comprises a liquid crystal layer.

10. An apparatus for measuring a thickness of a birefringence layer comprising:

a light source emitting a light having a single wavelength;

first and second polarizers set in parallel Nicol or in crossed Nicol in an optical path of the light;

an object to be measured having a birefringence layer in an optical path of a light between first and second polarizers in parallel Nicol or in crossed Nicol;

a $\lambda/2$ plate provided between the first and second polarizers; and

a photosensor for detecting a light transmitting said second polarizer.

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11. The apparatus according to Claim 10, further comprising a first means for rotating said object, and a second means for rotating said $\lambda/2$ plate.

12. The apparatus according to Claim 10, wherein said birefringence layer comprises a liquid crystal layer.

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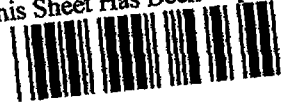


Fig. 1

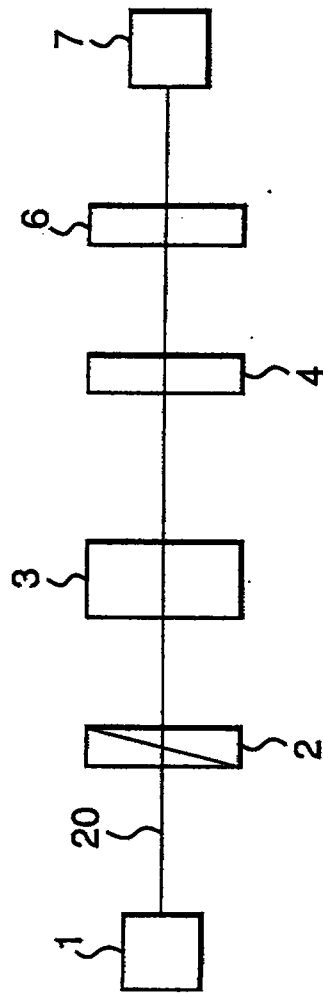


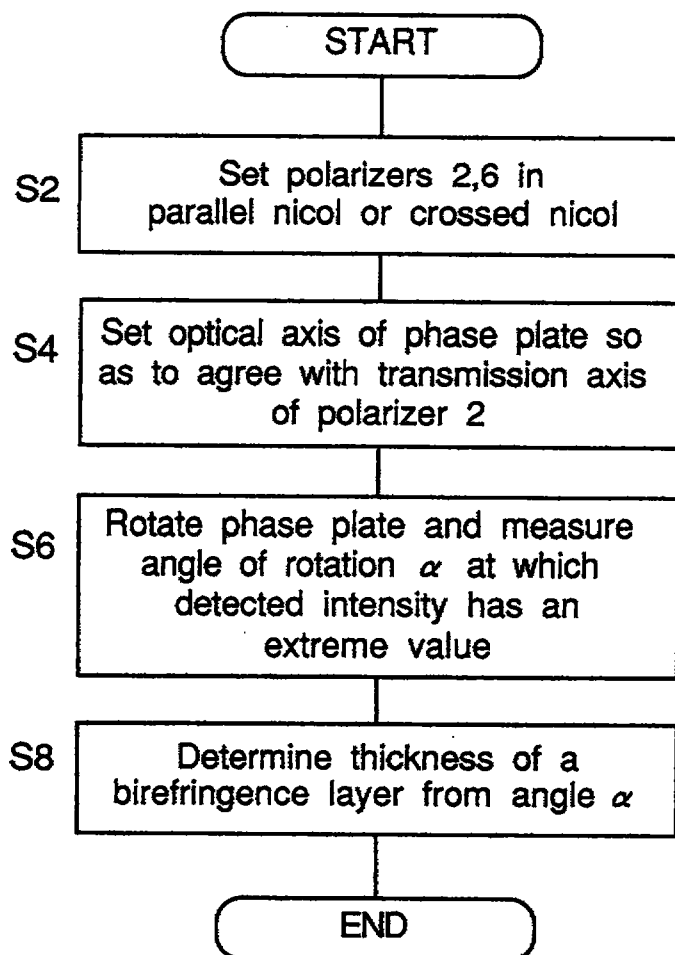
Fig.2

Fig.3

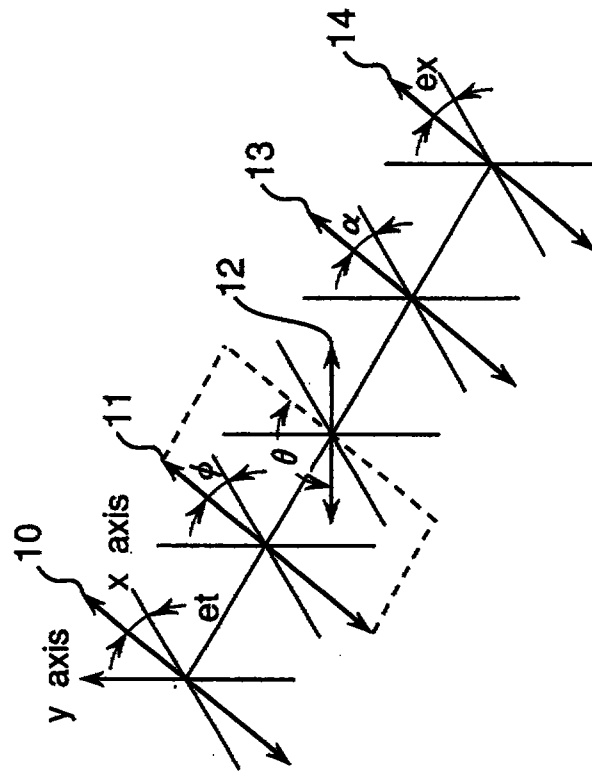


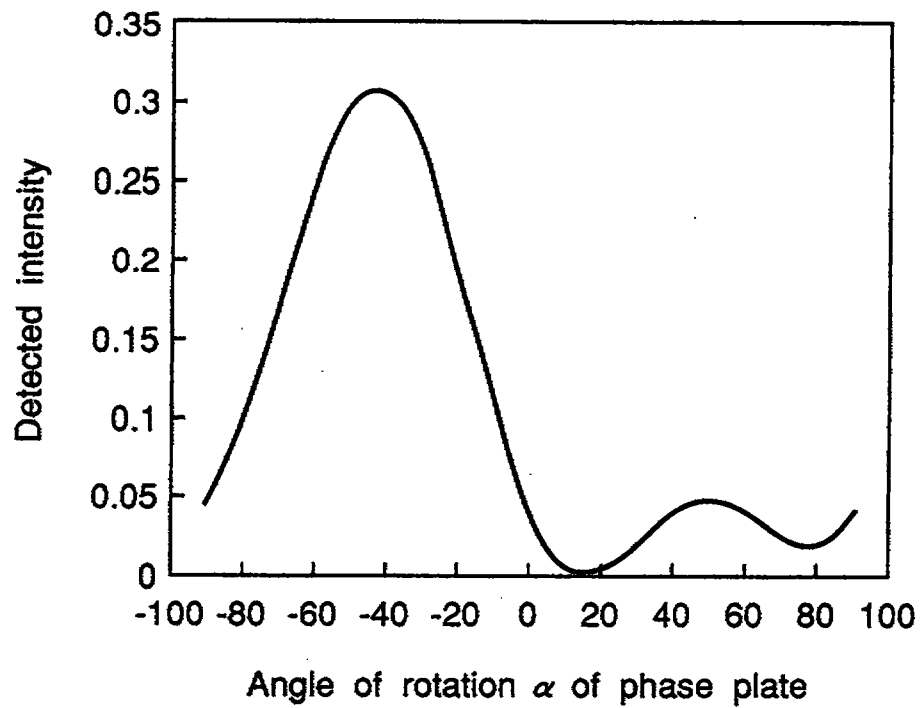
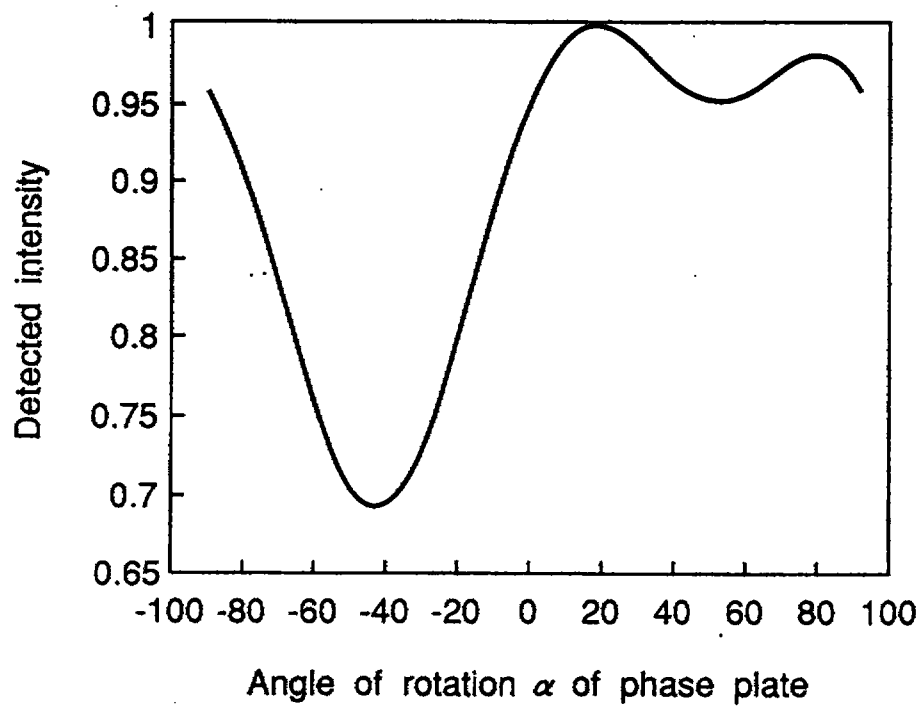
Fig.4*Fig.5*

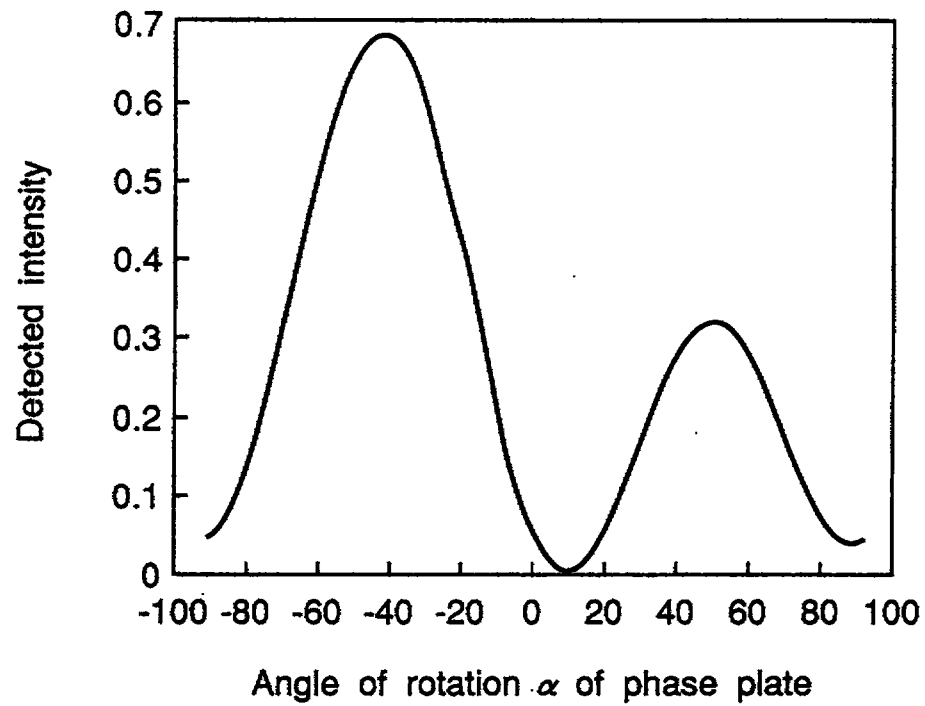
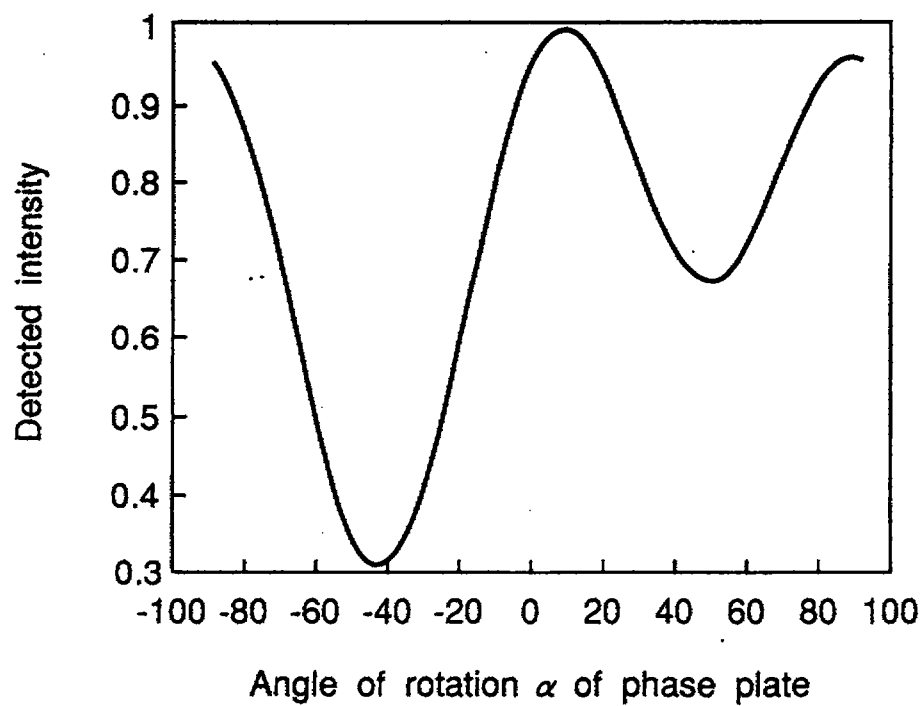
Fig.6*Fig.7*

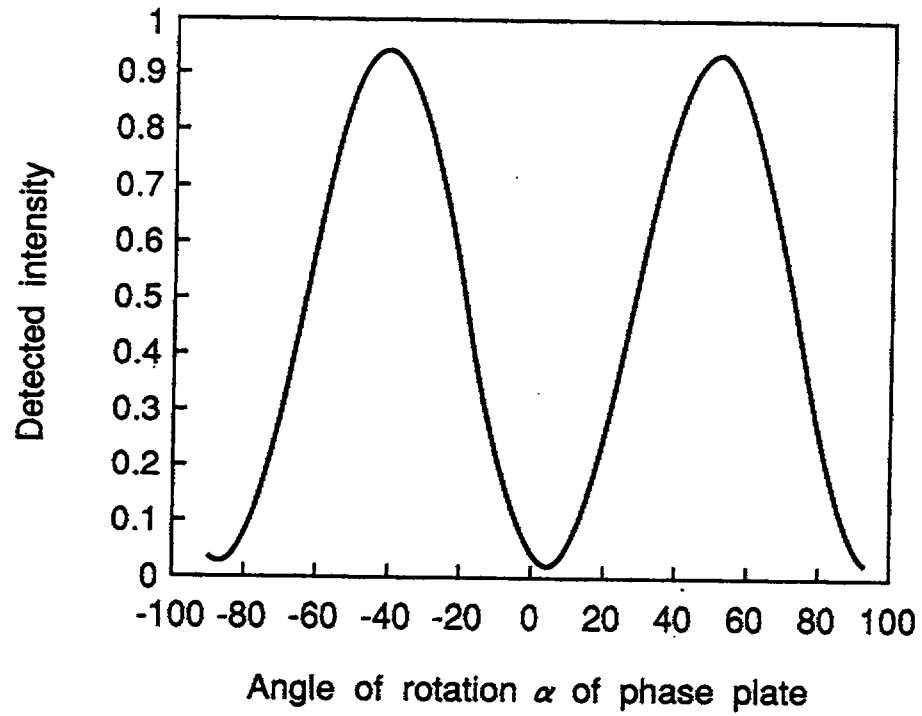
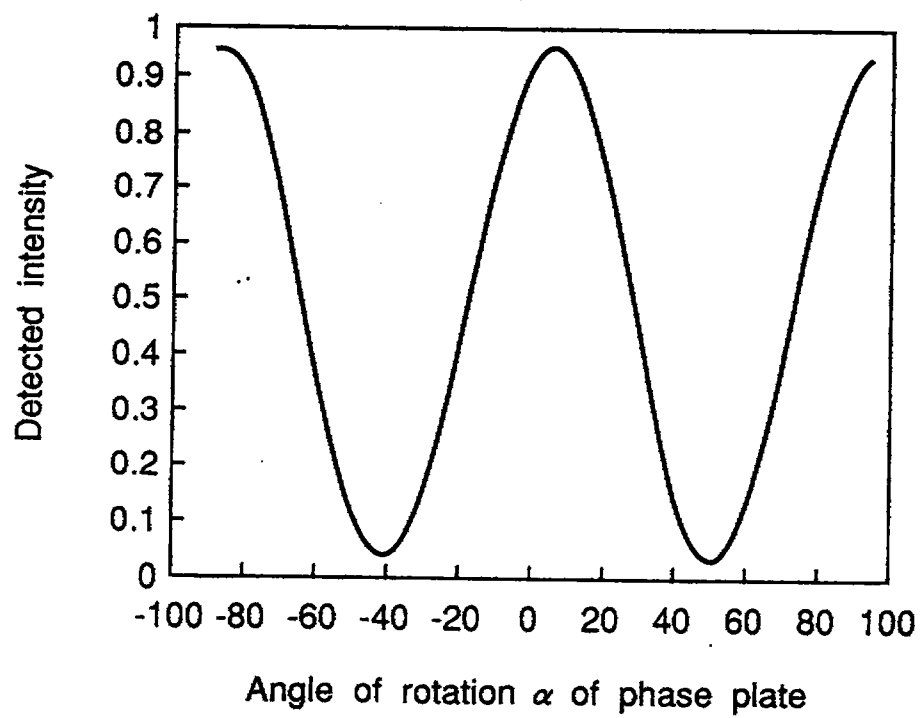
Fig.8**Fig.9**

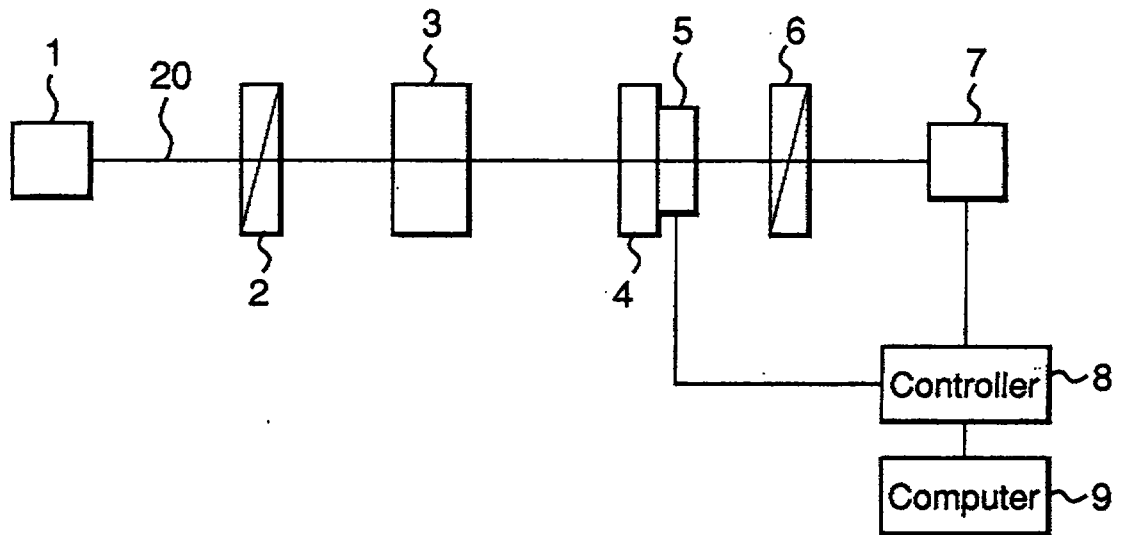
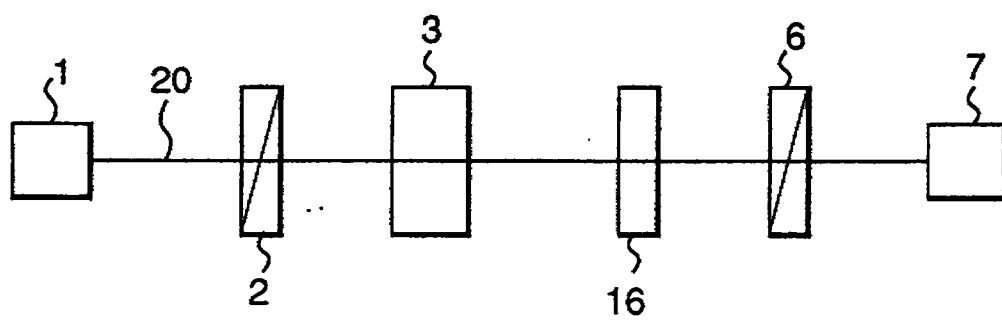
Fig.10*Fig.11*

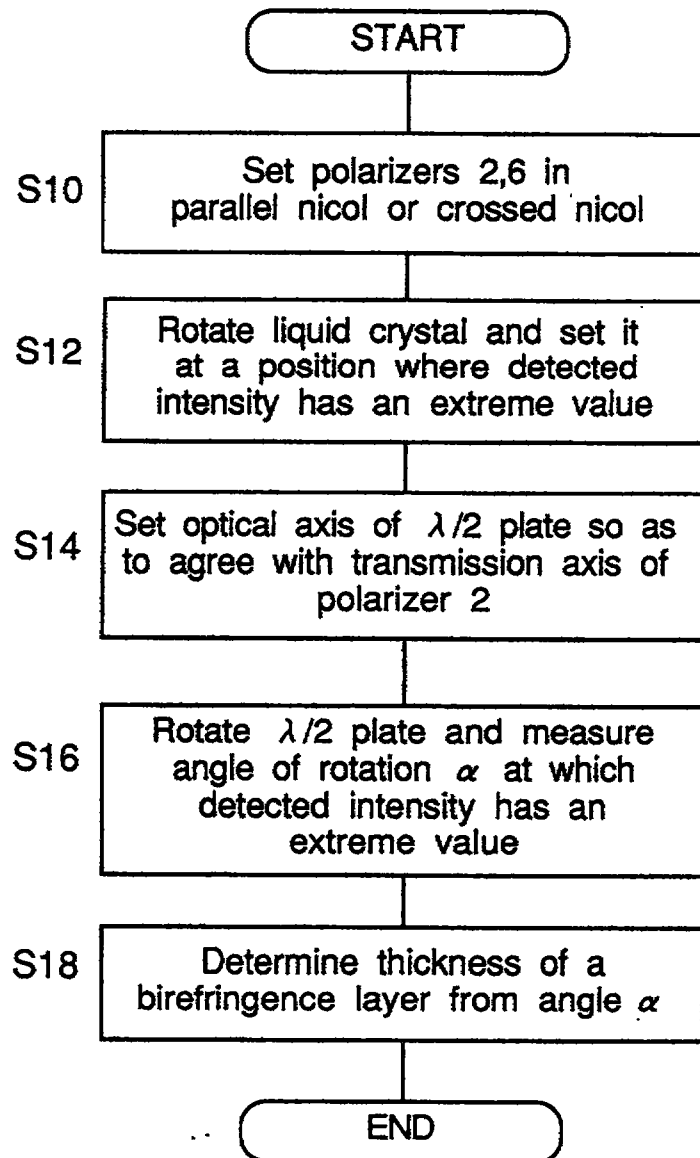
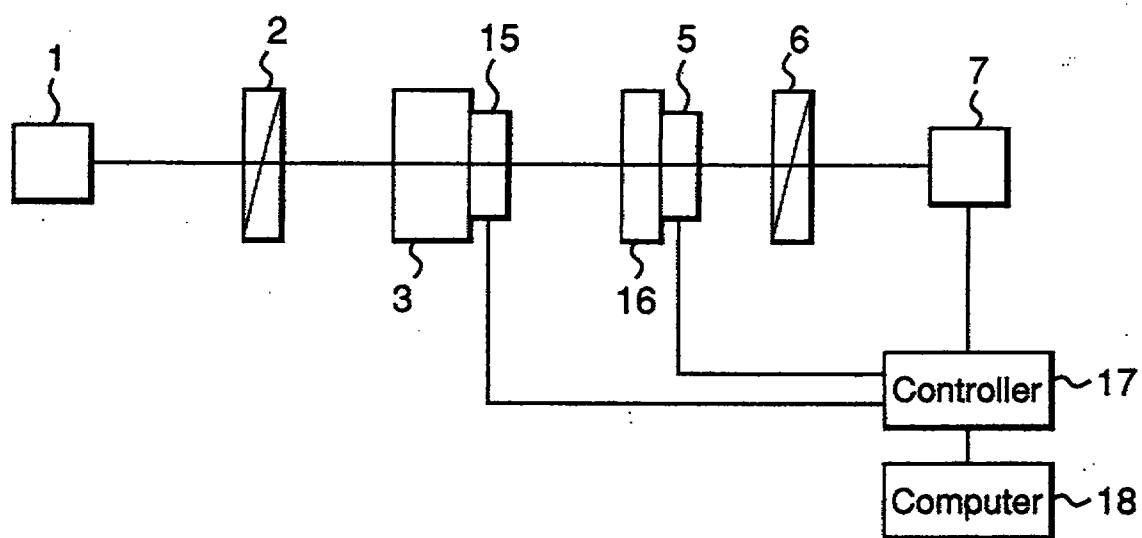
Fig.12

Fig.13

ABSTRACT OF THE DISCLOSURE

TITLE OF INVENTION: METHOD AND APPARATUS FOR MEASURING THICKNESS OF BIREFRINGENCE LAYER

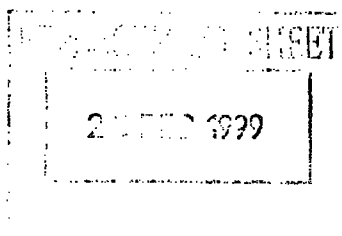
A liquid crystal layer 3 is set between two polarizers 2, 6 in parallel Nicol or in crossed Nicol, and a phase plate 4 is set between the two polarizers so that the transmission direction of the first polarizer agrees with the optical axis. Then, a rotation angle at which optical intensity transmitting the second polarizer has an extreme value to be determined, and the thickness of the birefringence layer is calculated according to the rotation angle of the phase plate 4. In a different method, a half-wave plate is used. First, the liquid crystal layer is set at a position where an optical intensity of the transmission light has an extreme value, and the half-wave plate provided between the two polarizers is set so that a transmission direction of the first polarizer agrees with the optical axis. Then, a rotation angle of the phase plate is determined at which an optical intensity of light transmitting the second polarizer has an extreme value. Then, the thickness is calculated according to the rotation angle of the half-wave plate. Thus, the thickness is measured in a short time even for a liquid crystal that does not have a twist angle of 90° or on which rubbing direction is not known.

Figure 2.

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An apparatus and a method for measuring a gap thickness are provided which can measure the gap thickness in a short time even for a liquid crystal which does not have a twist angle of 90° or on which rubbing direction is not known. An object to be measured liquid crystal (3) having a birefringence layer is set between two polarizers (2), (6) in parallel nicol or in crossed nicol, and a phase plate (4) is set between the two polarizers (2), (6) so that the transmission direction of the first polarizer agrees with the optical axis. As the phase plate is rotated, the quantity of light transmitting the second polarizer is changed. Thus, a rotation angle at which the quantity of transmission light has an extreme value can be determined, and the gap thickness of the birefringence layer of the liquid crystal (3) is calculated according to the rotation angle of the phase plate (4).



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☒	Claim : paged 15. to paged 17.	
☐	Abstract : paged to paged	
☐	Figure : paged to paged	
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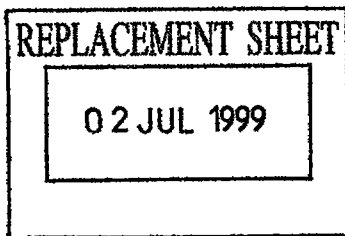
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However, the method explained above has several disadvantages. First, a liquid crystal layer on which the thickness can be measured is limited to a layer having a twist angle of about 90° . Further, it is needed to make the rubbing direction of the liquid crystal cell to the transmission direction of the two polarizers, the rubbing direction has to be known. However, it is usually difficult to measure the rubbing direction, and it is impossible to set the rubbing direction of the liquid crystal correctly to agree with the transmission direction of the two polarizers. Further, because the monochromatic meter or a spectrometer is needed, a time of about one minute is needed for measurement. Therefore, it cannot be applied to uses such as in-line inspection that need a high speed processing. Finally, because the monochromatic meter or a spectrometer is used, the apparatus has a complicated structure, and its cost is high.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a method and an apparatus for measuring a thickness of a birefringence layer correctly and at a high speed enough for in-line inspection, even for a liquid crystal that does not have a twist angle of 90° or on which rubbing direction is not known, and can be fabricated at a low cost.

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In accordance with the invention, there is provided a method for measuring a thickness of a birefringence layer comprising the steps of:

(a) providing an object to be measured having a birefringence layer in an optical path of a light having a single wavelength between first and second polarizers in parallel Nicol or
5 in crossed Nicol, transmission axis of said first polarizer being perpendicular to an optical axis of the light;

(b) providing a phase plate between said first and second polarizers so that a direction of transmission of said first polarizer agrees with the optical axis of the light, the object being interposed between said first polarizer and said phase plate;

10 (c) rotating said phase plate, and measuring a rotation angle of said phase plate at which an optical intensity of the light transmitting said second polarizer has an extreme value; and

(d) calculating a thickness of the birefringence layer according to the rotation angle of said phase plate.

15 In another aspect, there is provided an apparatus for measuring a thickness of a birefringence layer comprising:

a light source emitting a light having a single wavelength;

first and second polarizers set in parallel Nicol or in crossed Nicol in an optical path of the light, transmission axis of said first polarizer being perpendicular to an optical axis of
20 the light;

an object to be measured having a birefringence layer and provided between said first and second polarizers;

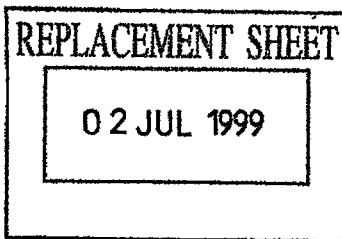
a phase plate provided between said first and second polarizers, the object being interposed between said first polarizer and said phase plate;

25 a rotator which rotates said phase plate;

a photosensor for detecting a light transmitting said second polarizer; and

a calculating means to calculate the thickness of the birefringence layer.

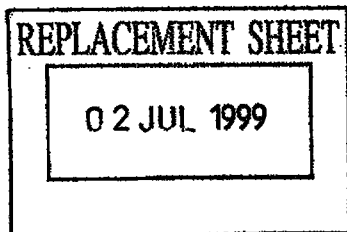
In another aspect, there is provided a method for measuring a thickness of a birefringence layer, the birefringence layer having an orientation direction at an incidence side thereof, the
30 method comprising the steps of:



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- (a) providing an object to be measured having a birefringence layer in an optical path of a light having a single wavelength between first and second polarizers in parallel Nicol or in crossed Nicol, transmission axis of said first polarizer being perpendicular to the optical axis of the light;
- 5 (b) rotating the object, and setting a position of the birefringence layer so that an optical intensity of the light transmitting said second polarizer has an extreme value;
- (c) providing a $\lambda/2$ plate between said first and second polarizers so that a direction of transmission of said first polarizer agrees with an optical axis of the light, the object being interposed between said first polarizer and said $\lambda/2$ plate;
- 10 (d) rotating said $\lambda/2$ plate, and measuring a rotation angle of said $\lambda/2$ plate at which an optical intensity of the light transmitting said second polarizer has an extreme value; and
- (e) calculating a thickness of the birefringence layer according to the rotation angle of the $\lambda/2$ plate.
- 15 In another aspect, there is provided an apparatus for measuring a thickness of a birefringence layer comprising:
- a lightsource emitting a light having a single wavelength;
- first and second polarizers set in parallel Nicol or in crossed Nicol in an optical path of the light, transmission axis of the first polarizer being perpendicular to an optical axis of
- 20 the light beam;
- an object to be measured having a birefringence layer in an optical path of a light between first and second polarizers in parallel Nicol or in crossed Nicol, the object being interposed between the first polarizer and the phase plate;
- a $\lambda/2$ plate provided between the first and second polarizers;
- 25 a rotator which rotates said phase plate;
- a photosensor for detecting a light transmitting said second polarizer; and
- a calculating means to calculate a thickness of the birefringence layer.



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An advantage of the present invention is that the thickness is measured at a high speed.

Another advantage of the present invention is that a liquid crystal cell having a twist angle other than 90° can be measured.

A further advantage of the present invention is that the thickness can be measured with a very simple optical system.

BRIEF DESCRIPTION OF THE DRAWINGS

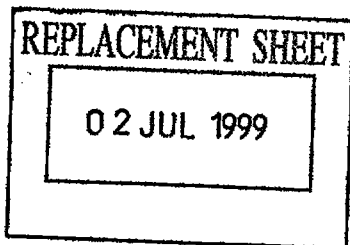
These and other objects and features of the present invention will become clear from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings, and in which:

Fig. 1 is a diagram of a basic optical system for a method for measuring a thickness of birefringence layer of a first embodiment of the invention;

Fig. 2 is a diagram of a flow of the measuring method of the first embodiment;

Fig. 3 is a diagram for explaining coordinates in the optical system of the embodiment;

Fig. 4 is a graph of detected intensity plotted against angle of rotation of a phase plate in a case of the



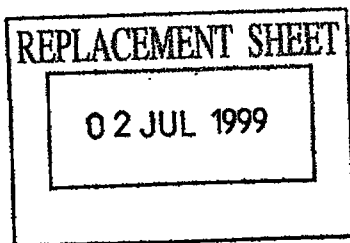
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What is claimed is:

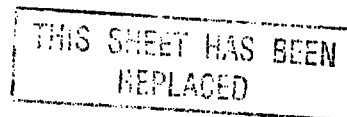
1. A method for measuring a thickness of a birefringence layer comprising the steps of:
 - (a) providing an object to be measured having a birefringence layer in an optical path of a light having a single wavelength between first and second polarizers in parallel Nicol or
5 in crossed Nicol, transmission axis of said first polarizer being perpendicular to an optical axis of the light;
 - (b) providing a phase plate between said first and second polarizers so that a direction of transmission of said first polarizer agrees with the optical axis of the light, the object being interposed between said first polarizer and said phase plate;
 - 10 (c) rotating said phase plate, and measuring a rotation angle of said phase plate at which an optical intensity of the light transmitting said second polarizer has an extreme value; and
 - (d) calculating a thickness of the birefringence layer according to the rotation angle of said phase plate.
- 15 2. The method according to Claim 1, wherein said phase plate comprises a Babinet-Soleil compensator.
3. The method according to Claim 1, wherein said birefringence layer comprises a liquid crystal layer.
4. An apparatus for measuring a thickness of a birefringence layer comprising:
20 a light source emitting a light having a single wavelength;
first and second polarizers set in parallel Nicol or in crossed Nicol in an optical path of the light, transmission axis of said first polarizer being perpendicular to an optical axis of the light;
an object to be measured having a birefringence layer and provided between said first
25 and second polarizers;
a phase plate provided between said first and second polarizers, the object being interposed between said first polarizer and said phase plate;
a rotator which rotates said phase plate;
a photosensor for detecting a light transmitting said second polarizer; and
30 a calculating means to calculate the thickness of the birefringence layer.





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5. The apparatus according to Claim 4, further comprising a means for rotating said phase plate.
6. The apparatus according to Claim 4, wherein said phase plate comprises a Babinet-Soleil compensator.
- 5 7. The apparatus according to Claim 4, wherein said birefringence layer comprises a liquid crystal layer.
8. A method for measuring a thickness of a birefringence layer, the birefringence layer having an orientation direction at an incidence side thereof, the method comprising the steps of:
- 10 (a) providing an object to be measured having a birefringence layer in an optical path of a light having a single wavelength between first and second polarizers in parallel Nicol or in crossed Nicol, transmission axis of said first polarizer being perpendicular to the optical axis of the light;
- (b) rotating the object, and setting a position of the birefringence layer so that an
- 15 optical intensity of the light transmitting said second polarizer has an extreme value;
- (c) providing a $\lambda/2$ plate between said first and second polarizers so that a direction of transmission of said first polarizer agrees with an optical axis of the light, the object being interposed between said first polarizer and said $\lambda/2$ plate;
- (d) rotating said $\lambda/2$ plate, and measuring a rotation angle of said $\lambda/2$ plate at
- 20 which an optical intensity of the light transmitting said second polarizer has an extreme value; and
- (e) calculating a thickness of the birefringence layer according to the rotation angle of the $\lambda/2$ plate.
9. The method according to Claim 8, wherein said birefringence layer comprises a liquid
- 25 crystal layer.
10. An apparatus for measuring a thickness of a birefringence layer comprising:
- a lightsource emitting a light having a single wavelength;
- first and second polarizers set in parallel Nicol or in crossed Nicol in an optical path of the light, transmission axis of the first polarizer being perpendicular to an optical axis of
- 30 the light beam;



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an object to be measured having a birefringence layer in an optical path of a light between first and second polarizers in parallel Nicol or in crossed Nicol, the object being interposed between the first polarizer and the phase plate;

a $\lambda/2$ plate provided between the first and second polarizers;

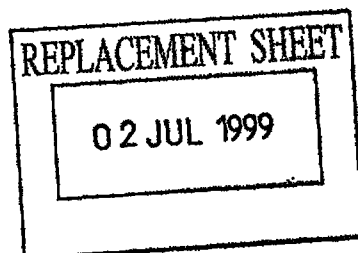
5 a rotator which rotates said phase plate;

a photosensor for detecting a light transmitting said second polarizer; and

a calculating means to calculate a thickness of the birefringence layer.

11. The apparatus according to Claim 10, further comprising a first means for rotating said object, and a second means for rotating said $\lambda/2$ plate.

10 12. The apparatus according to Claim 10, wherein said birefringence layer comprises a liquid crystal layer.



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5. ~~The apparatus according to Claim 4, further comprising a means for rotating said phase plate.~~

6. The apparatus according to Claim 4, wherein said phase plate comprises a Babinet-Soleil compensator.

7. The apparatus according to Claim 4, wherein said birefringence layer comprises a liquid crystal layer.

8. A method for measuring a thickness of a birefringence layer, the birefringence layer having an orientation direction at an incidence side thereof, the method comprising the steps of:

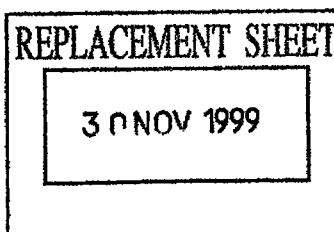
(a) providing an object to be measured having a birefringence layer in an optical path of a light having a single wavelength between first and second polarizers in parallel Nicol or in crossed Nicol, transmission axis of said first polarizer being perpendicular to the optical axis of the light;

(b) rotating the object, and setting a position of the birefringence layer so that an optical intensity of the light transmitting said second polarizer has an extreme value;

(c) providing a $\lambda/2$ plate between said first and second polarizers so that a direction of transmission of said first polarizer agrees with an optical axis of the light, the object being interposed between said first polarizer and said $\lambda/2$ plate;

(d) rotating said $\lambda/2$ plate, and measuring a rotation angle of said $\lambda/2$ plate at which an optical intensity of the light transmitting said second polarizer has an extreme value; and

(e) calculating a thickness of the birefringence layer according to the rotation angle of the $\lambda/2$ plate.



9. The method according to Claim 8, wherein said birefringence layer comprises a liquid crystal layer.

10. An apparatus for measuring a thickness of a birefringence layer comprising:

a lightsource emitting a light having a single wavelength;

first and second polarizers set in parallel Nicol or in crossed Nicol in an optical path of the light, transmission axis of the first polarizer being perpendicular to an optical axis of the light beam;

an object to be measured having a birefringence layer in an optical path of a light between first and second polarizers in parallel Nicol or in crossed Nicol;

a $\lambda/2$ plate provided between the first and second polarizers, the object being interposed between the first polarizer and the $\lambda/2$ plate;

a rotator which rotates said $\lambda/2$ plate;

a photosensor for detecting a light transmitting said second polarizer; and

a calculating means to calculate a thickness of the birefringence layer.

11. The apparatus according to Claim 10, further comprising a means for rotating said object.

12. The apparatus according to Claim 10, wherein said birefringence layer comprises a liquid crystal layer.

