Polarization measurement with EZContrast

1 Why measuring polarization state with angle ?

LCD operation and optimization are very dependent of the use of sophisticated polarization compensation. The aims of these compensators are:

- To optimize overall polarization state in order to achieve highest contrast.
- To optimize polarization state with angle in order to achieve highest contrast over a wide angle.

Common strategies are to introduce films in order to obtain at the output of the optical stack composed of the films and LC cell a polarization state that is the closest possible to a linearly polarized one. This must be achieved for all wavelengths and all angles at the best. This work is usually carried out for the black state of the display – in order to maximize contrast – although optimizing the white state is also important.

By placing the analyzer perpendicular to this linearly polarized output state, a display with good viewing angle and wavelength dependence can be obtained.

Having the ability of quickly measuring the polarization state at the output of a cell assembly is of great importance:

- In order to check the quality of the "linearized state" as explained above.
- In order to quickly verify theoretical work or actual properties of a film.
- In order to check a candidate solution for improving display quality and experimentally understand and/or check how it works.

This kind of work previously needed complicated and time-consuming procedures and equipments. We will show below how this can be carried out by using EZContrast or EZLite equipment together with suitable analysis software.

2 Basic Formulae

Considering an elliptically polarized light as shown on Figure #1, it can be demonstrated that when the light is analyzed through a polarizer whose polarization direction is at angle θ, the intensity is given by :

$$I = A_0 (1 + \cos 2\varepsilon \cos 2(\theta - \alpha)) / 2 \qquad [1]$$

Where:

- ε is the ellipticity angle given by $tg\ \varepsilon = b/a$
- α is the angle of the ellipse with respect to OX axis

3 Use of the formulae for measurement of polarization characteristics maps

3.1 Fully Polarized light

There are 3 unknown variables (I_0, α and ε) to be determined. Only two of them are of interest (α and ε). Three measurements should be sufficient for, from a measurement with OFT equipment - EZContrast or EZLite, deriving these two values for each angle.

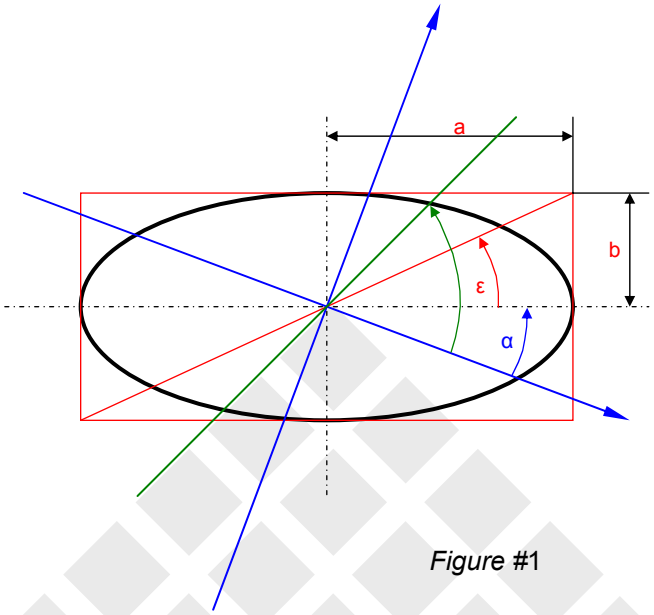

Figure #1

We can chose to measure at 0, π/4 and π/2:

$$I_0 = = A_0 (1 + \cos 2\varepsilon \cos 2(-\alpha)) / 2 = A_0 (1 + \cos 2\varepsilon \cos 2\alpha) / 2 \quad [2]$$

$$I_{\pi/4} = = A_0 (1 + \cos 2\varepsilon \cos (\pi/2 - 2\alpha)) / 2 = A_0 (1 + \cos 2\varepsilon \sin 2\alpha) / 2 \quad [3]$$

$$I_{\pi/2} = = A_0 (1 + \cos 2\varepsilon \cos (\pi - 2\alpha)) / 2 = A_0 (1 - \cos 2\varepsilon \cos 2\alpha) / 2 \quad [4]$$

It can be shown that, from [2] and [3]:

$$I_0 + I_{\pi/2} = A_0 \quad [5]$$

$$I_0 - I_{\pi/2} = A_0 \cos 2\varepsilon \cos 2\alpha \quad [6]$$

$$I_0 - I_{\pi/4} = A_0 \cos 2\varepsilon (\cos 2\alpha - \sin 2\alpha) / 2 \quad [7]$$

$$I_0 - I_{\pi/2} - 2 (I_0 - I_{\pi/4}) = 2 I_{\pi/4} - I_0 - I_{\pi/2} = A_0 \cos 2\varepsilon \sin 2\alpha \quad [8]$$

From [6] and [8], it yields:

$$(2 I_{\pi/4} - I_0 - I_{\pi/2}) / (I_0 - I_{\pi/2}) = \sin 2\alpha / \cos 2\alpha = \operatorname{tg} 2\alpha \quad [9]$$

[9] can be used to compute α. And is given by:

$$\alpha = \tfrac{1}{2} \operatorname{arctg} ((2 I_{\pi/4} - I_0 - I_{\pi/2}) / (I_0 - I_{\pi/2})) \quad [10]$$

Argument of arctg ranging between $-\infty$ and $+\infty$, signs of both numerator and denominator of above arctg argument are known. Then α values will range between -π/2 and + π/2.

Then from [5] and [6], and α being previously computed, it yields:

$$(I_0 - I_{\pi/2}) / (I_0 + I_{\pi/2}) = \cos 2\varepsilon \cos 2\alpha \quad [11]$$

$$\varepsilon = \tfrac{1}{2} \arccos ((I_0 - I_{\pi/2}) / [\cos 2\alpha (I_0 + I_{\pi/2})]) \quad [12]$$

Argument of arcos should range between 0 and +1, thus giving a value of ε bound between 0 and π/4.

3.2 Partially polarized light

If partially polarized light (of intensity A_1) is contained in the signal, [1] becomes:

$$I = A_0 (1 + \cos 2\varepsilon \cos 2(\theta - \alpha)) / 2 + A_1 / 2$$

$$= (A_0 + A_1) (1 + (A_0 / (A_0 + A_1)) \cos 2\varepsilon \cos 2(\theta - \alpha)) / 2$$

$$= A (1 + K \cos 2\varepsilon \cos 2(\theta - \alpha)) / 2 \qquad [14]$$

With $K = (A_0 / (A_0 + A_1)$.

With above described method (cf 3.1 : Fully Polarized Light), it will not be possible to distinguish between influence of ellipticity (cos 2ε term) and partial polarization (K term).

A method for measuring partially polarized light is currently under development.

4 Polarization Measurements with EZContrast and EZCom

4.1 Measurement principle

EZContrast and EZLite range of equipment are tools that provide a way to convert angular distribution of light in a planar distribution. This is achieved by making the Optical Fourier Transform of the plane waves emitted by the sample in every direction.

EZContrast and EZLite products, having been designed in order to have the minimal polarization introduced by the optics, can be used to analyze – through the above-described method – the polarization state at each point of the Fourier distribution.

It must be noticed that α and ε angles derived by the method will be relative to the coordinate system attached to each direction.

In order to carry out the required measurement, polarizing cartridges are used instead and in place of the normal cartridges. 3 of them are needed.

4.2 Basic measurements

Analysis of polarization with angle needs to carry out 3 measurements. These measurements are made successively on the same sample. Each of them is carried out with a special polarizing filter.

These filters are, at this time, held by the NDensity cartridge and successively inserted in place of the usual NDensity option. They are numbered 0, PI/4 and PI/2.

- The "0" polarizing filter is selecting horizontal waves.
- The "PI/4" polarizing filter is selecting waves at 45° from horizontal axis.
- The "PI/2" polarizing filter is selecting vertical waves.

Analysis of the obtained measurements is made according to the above method (cf 3.1 : Fully Polarized Light). Some recommendations and remarks follow:

- As ratios will be made between the measurements, these must be done when the light output level of the device is stable. Using measurements from various devices or from the same device at different output levels may produce unpredictable and/or unreliable results.
- Polarization parameters may vary according to the wavelength. It is recommended to set the measurement style in order to use only one color filter (YB filter has a maximum at 500 nm) or to use an illumination equipment at a selected wavelength. ELDIM may provide additional interference filters at selected wavelength if necessary.

- (Not implemented yet) Three different measurement styles can be settled in order to automatically set the label of the three measurements and to allow faster further analysis.

4.3 Computing the polarization characteristics

The analysis is done as follows:

- Set the label of the three successive measurement using "*Analysis | Polarization | Select Acquisition | At 0°*", "*Analysis | Polarization | Select Acquisition | At 45°*" or "Analysis | Polarization | *Select Acquisition | At 90°*".
- The menu "*Analysis | Polarization | Compute*" should be enabled.
- Using this menu enables to carry out the required computation and produces the final plot.

This plot (See Figure 2) gives for each angle:

- The ellipticity factor tg ε = b/a
- The inclination angle α

This plot can be further printed and copy/pasted as usual. It can be stored in a PAF (Polarization Analysis File) for later reference.

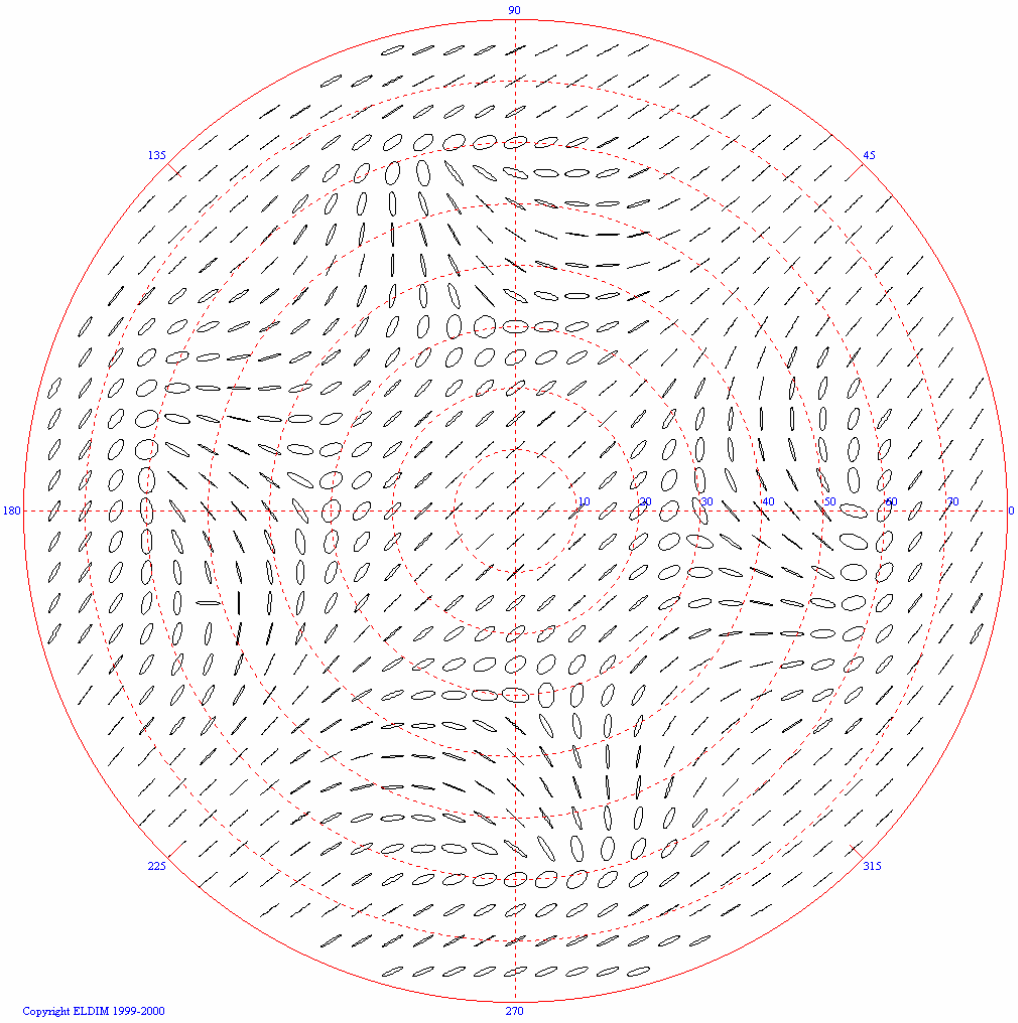

Figure #2

This plot gives a visual representation of the polarized state at each angle. By using it, users can:

- Judge of the quality of a LC cell compensation technique.

- Analyze the behavior of a new product.
- Understand graphically what is happening in their product.

4.4 Additional functions (Not implemented yet)

The Edit menu allows to extract polar plots (EDF files) of:

- The ellipticity factor tg ε = b/a
- The inclination angle α

These plots can be further analyzed with usual EDF tools.

We think that additional information can be further drawn from the results and method described above. We are open to any request for new ways to analyze and draw this data. Customers requests and ideas are most welcomed.

4.5 Automation of the three measurements

Automation of the overall process can be done with ActiveX functions.

5 Reaching Us…

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