# O- and E-polarizers and advanced optical films for LCDs based on Lyotropic Dichroic Dyes

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## Abstract.

*Polarizers with high polarizing efficiency and other advanced optical films based on Lyotropic Dichroic Dyes have been developed for LCD and other applications. The developed optical films reveal both rod-like chromophores structure in a case of positive, or O-films and disc-like one for negative, or E-film.*

## 1. Introduction

The polarizers for LCD are polymer films oriented by the uni-axial stretching and dyed by iodine compounds. They reveal high polarization efficiency and "parallel" transmission, but have a number of drawbacks: relative high cost, low thermal stability and durability, and relatively high thickness (up to 200 μm).

Polarizers, based on molecular oriented Lyotropic Dichroic Dyes (LDD) [1,2] may be proposed as a breakthrough solution of the above issues. Materials for these polarizers have been developed by NIOPIK [1] and Optiva Inc. [2]. The polarizers possess high thermal stability (working temperature up to 200°C) and small thickness (<1 μm), and therefore could be used as "in-cell" polarizers in LCD. Unfortunately, the polarizing properties of these first-generation (1G) materials are rather poor in comparison with iodine polarizers, mainly because of their disc-like chromophore structure (E-polarizers [3], Fig.1).

Recently we developed the second-generation (2G) LDD polarizers [4-6], featuring a rod-like chromophore structure (Fig.1). The developed polarizers are O-polarizers, because they absorb the extraordinary wave of light (polarized along the coating direction) and transmit the ordinary wave of light (polarized perpendicular to the coating direction). The optical properties of the 2G LDD O-polarizer have a superiority over E-polarizer and are close to those of the iodine polarizer.

Also we continue the development of other advanced optical films based on lyotropic dichroic dyes for LCD. Here we would like to review shortly the new opportunities of these film.

## 2. Materials and optical film technology

At certain concentration the aqueous solutions of dichroic dyes form a lyotropic liquid crystal phase wherein the dyes molecules are highly ordered. By deposition of LDD materials onto the surface of various polished substrates made of glass, plastic, etc. the wet layer is formed wherein the dyes molecules chromophores are oriented *along* or *perpendicular* to the coating direction. After drying the thin (0.1-1 μm) polarizing and/or birefringent coatings are formed. Optical properties for LDD based films depend on both dichroic dyes itself and a method of coating and drying. The structure, color, polarizing properties and/or retardation of LDD film depend on dyes compositions and can vary by change of dyes proportions and additives in lyotropic liquid crystal compositions. The use of mixture of various dyes allows to cover a broad range of the wavelengths. For birefringent coating transparent at visible wavelengths the dichroic dyes with absorption bands beyond of visible range are used.

## 3. Dichroic O- and E-polarizers

The most critical parameter for all polarizers is Dichroic Ratio (DR). Basing on DR value it is possible to calculate polarizers "crossed" transmission at fixed "parallel" transmission, and vise versa. In accordance with definition $DR_O = k_e / k_o$ for O-polarizers with rod-like chromophores ($k_e$ and $k_o$ – absorption coefficients), and $DR_E = k_o / k_e$ for E-polarizers with disc-like chromophores.

It is easy to show [6], that under the condition of equality of the average fluctuations for molecular chromophores, the dichroic ratio for O-polarizer is four times higher, than in a case of E-polarizers one:

$$DR_O / DR_E = 4$$

To compare O- and E-polarizers behavior at an inclination we have simulated "parallel" transmission Ho, "crossed" transmission $H_{90}$, and contrast ratio CR = Ho / $H_{90}$ for the O-O, E-E and combined O-E polarizers pairs. To focus on transmission at an inclination only we presume for simplicity the Dichroic Ratio to be equal 100 for both O- and E-polarizers and then compared parallel transmission for those pairs assuming Ho at normal incidence to be equal. The results are shown in Fig.2 for 0° azimuth (inclination is along polarizers axes), 90° azimuth (inclination is perpendicular to polarizers axes), and at 45° azimuth. It is clearly seen that if at least one E-polarizer is included in polarizers pair the parallel transmission Ho falls sharply with inclination except the 90° azimuth inclination. The

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following explanation of the fact can be offered. In E-polarizers Z-component of absorption (perpendicular to the polarizer plane at normal incidence) is "crossed" at an inclination with Y-component of absorption (which is parallel to the polarizer plane but perpendicular to polarizer axis). Only at the 90° azimuth inclination with respect to E-polarizer axis this "crossing" does not arise. The O-O polarizers pairs do not reveal this phenomenon at all.

We also have simulated Ho, $H_{90}$ and CR at 45° azimuth inclination for real O-O polarizers pair with Dichroic Ratio DR=100 and for real E-E polarizers pair with Dichroic Ratio DR=25 (Fig.3). Parallel transmission Ho of the O-O polarizers in comparison with the E-E polarizers turns out to be much higher due to the rod-like chromophore structure.

Contrast Ratio values are also much higher for the O-O polarizer pair at almost any inclination angle even if the well known effect of the light leakage of the crossed O-O pair at 45° azimuth inclination would be taken into account. We would like to note, no retardation films were taken into consideration to compensate this leakage.

In advanced LCD O-O iodine polarizers pair is used together with a compensation films. In this case O-O polarizers light leakage at LCD inclination is almost eliminated, and LCD contrast ratio increases significantly. But LCD brightness at an inclination depends mainly on "parallel" transmission Ho, and the advantage of O-polarizers becomes evident.

We have measured also the transmission spectra of our LDD O-polarizer 65a-MK-03 for transmissive LCD (Fig.4). Detailed comparison (especially for "crossed" transmission $H_{90}$ ) shows that our LDD O-polarizer 65a-MK-03 for transmissive LCD is very close to modern iodine polarizer.

## 4. Reflective polarizers.

Reflective type polarizers are developed also using LDD birefringent materials. These polarizers consist of one or more LDD and isotropic layer(s) with different optical properties. The thickness of isotropic and birefringent anisotropically absorbing LDD layer satisfies the condition of obtaining at output of the polarizer interference extremum at least for one linearly-polarized light component (Fig.5).

The first feature of our LDD materials is very high value of refractive index (a maximal value is no less than 1.9). For this reason a reflection from each layer is rather high (Fig.5). Therefore, the number of layers needed to reach 90-95% reflection of linear polarized light from multi-layer structure is decreased dramatically with respect to DBEF film from 3M (3-10 vs. 500-900).

The second feature of our LDD materials is the spectral bands with abnormal dispersion of refractive index (refractive index grows as the polarized light wavelength increases, Fig.6). In some cases refractive index is directly proportional to the polarized light wavelength. In these cases the result of constructive interference for beams reflected from interlayer zones is independent of wavelength (so called achromatic interference is realized).

## 5. Compensation films

The various compensation films are possible to create basing on retardation / birefringent properties of oriented layers of Lyotropic *Dichroic Dyes, which are transparent at visible wavelengths.

Plus A-film (+A-film) is created as homogenously planar oriented positive LDD layer with optical axis parallel to layer surface (Fig.7). Plus C-film (+C-film) is created as homogenously oriented positive LDD layer with optical axis perpendicular to layer surface. Minus A-film (-A-film) is created as homogenously planar oriented negative LDD layer with optical axis parallel to layer surface. Minus C-film (-C-film) is created as homogenously oriented negative LDD layer with optical axis perpendicular to layer surface. These type of compensation films are used for In-Plane-Switching (IPS) LCD and Vertically-Aligned (VA) LCD compensation.

Compensation oblique films for TN-LCD are realized at different local optical axis alignment on film surfaces: perpendicular alignment on first surface of film and parallel on another one (-S and +S-films, Fig.7). Negative LDD material is used to obtain -S-films, which are the analogies of discotic WA films from Fuji Photo Film.

Retardation vs. wavelength (dispersion) of mentioned compensation films is controlled using LDD materials with different spectral position of absorption bands.

## 5. Conclusions

The developed O- and E-polarizers and other advanced optical films based on Lyotropic Dichroic Dyes are very promised for LCD industry and other application.

The features of LDD based advanced optical films are high optical performance, low cost, small thickness (< 1 μm), high working temperatures (up to 200° C), and high durability.

Dichroic Ratio of 2G O-polarizers with rod-like chromophores is four times larger than one of 1G E-polarizers based on disk-like chromophores. O-polarizers reveal much higher parallel transmission Ho and contrast ratio than ones of E-polarizers at normal incidence (due to higher dichroic ratio) and at an inclination (due to rod-like chromophores structure itself).

LDD based optical films are useful as compensation films for VA-, IPS- and TN-LCD.

## 6. References

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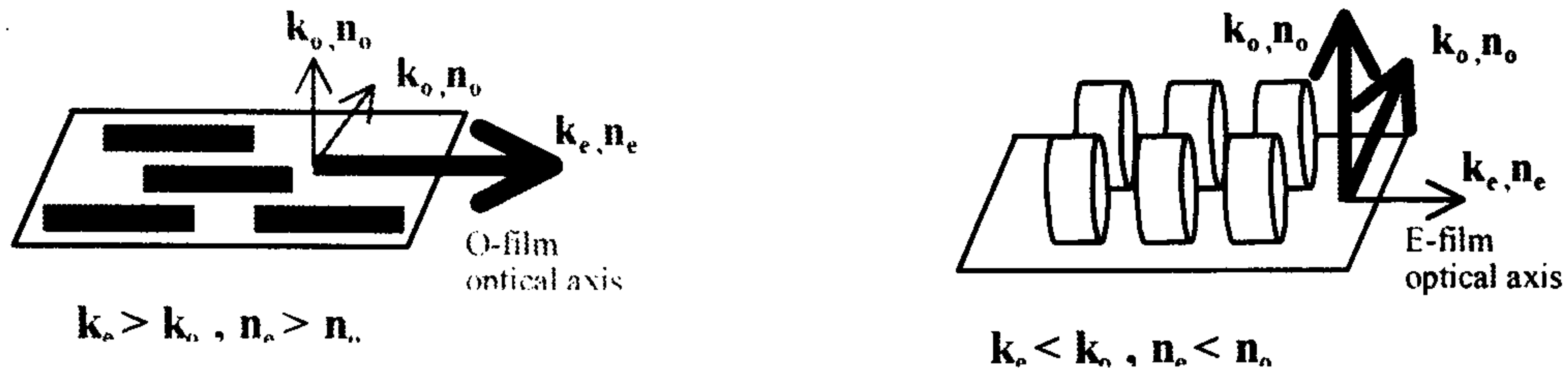



Fig.1 Positive O- and negative E-films chromophore

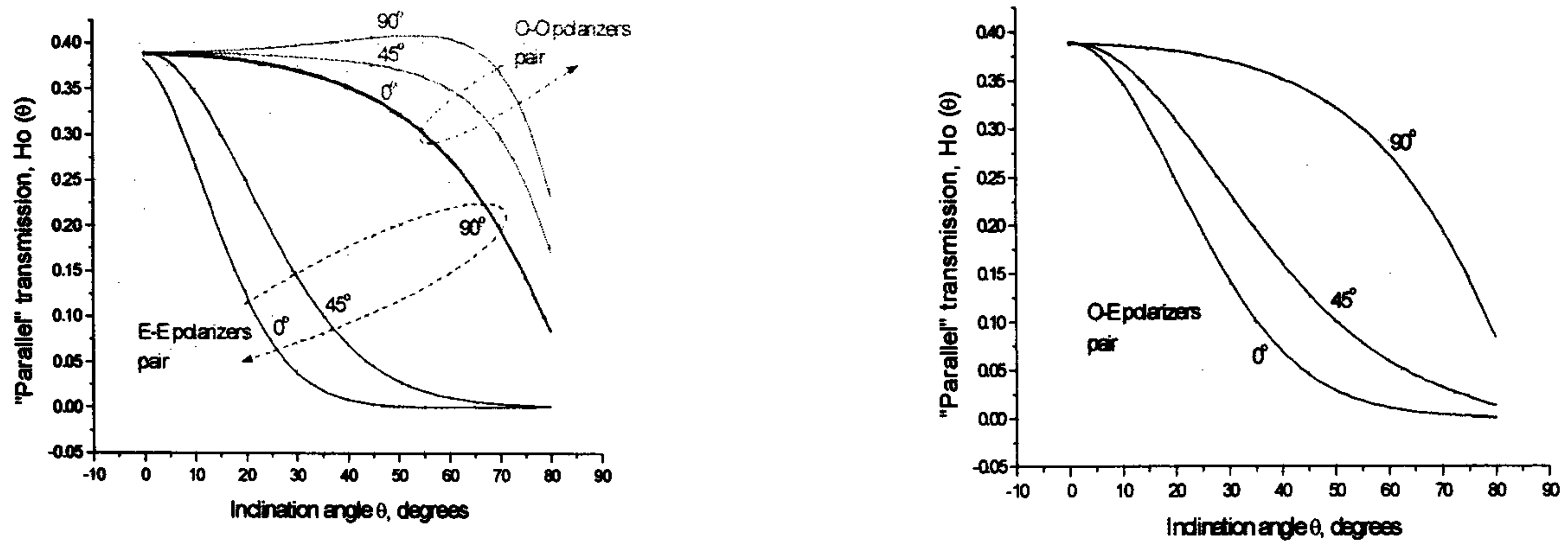
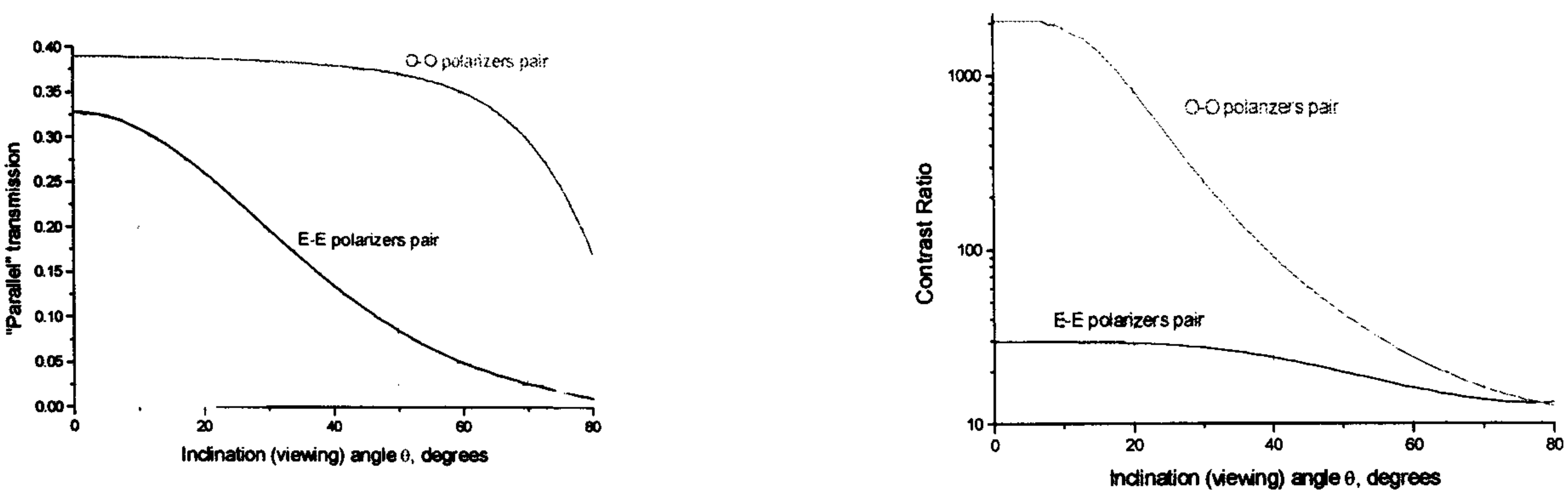



Fig. 2 "Parallel" transmission Ho vs. inclination angle (0°, 45°, 90° azimuths) for O-O, E-E, and O-E polarizers pairs



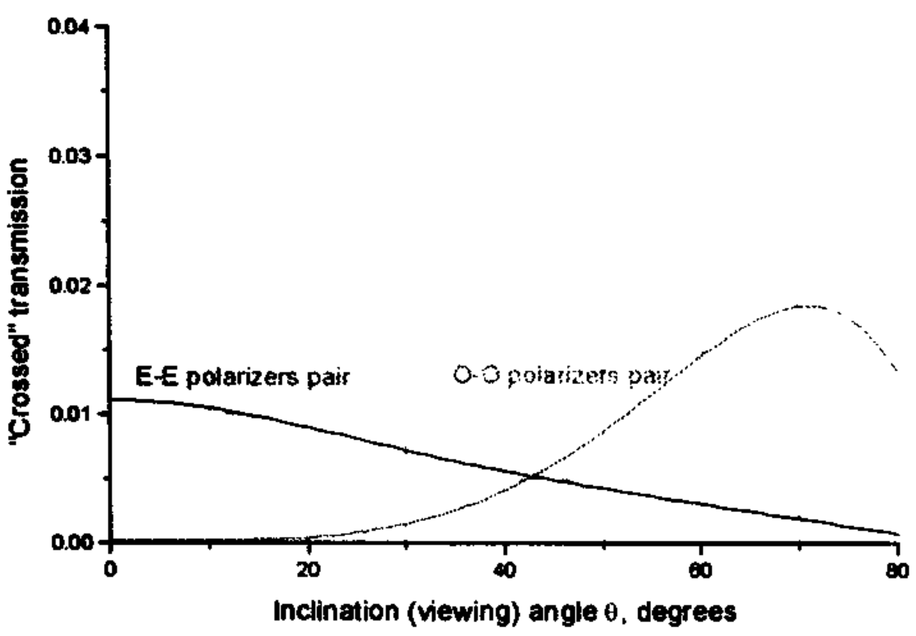




Fig.3 "Parallel" transmission Ho, "crossed" transmission $H_{90}$ and Contrast Ratio vs. inclination angle for real O-O and E-E polarizers ( $DR_O = 100$ , $DR_E = 25$, 45° azimuth inclination)

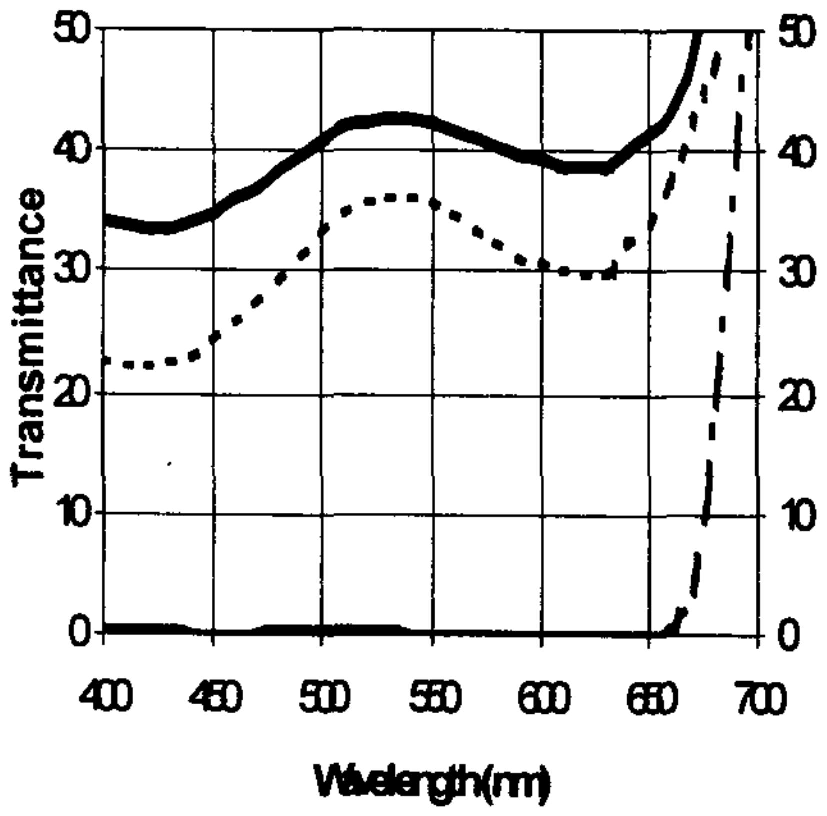



Fig. 4 "Single" transmission To, "parallel transmission Ho and "crossed" transmission $H_{90}$ spectra of LDD O-polarizer 65a-MK-03 for transmissive LCD

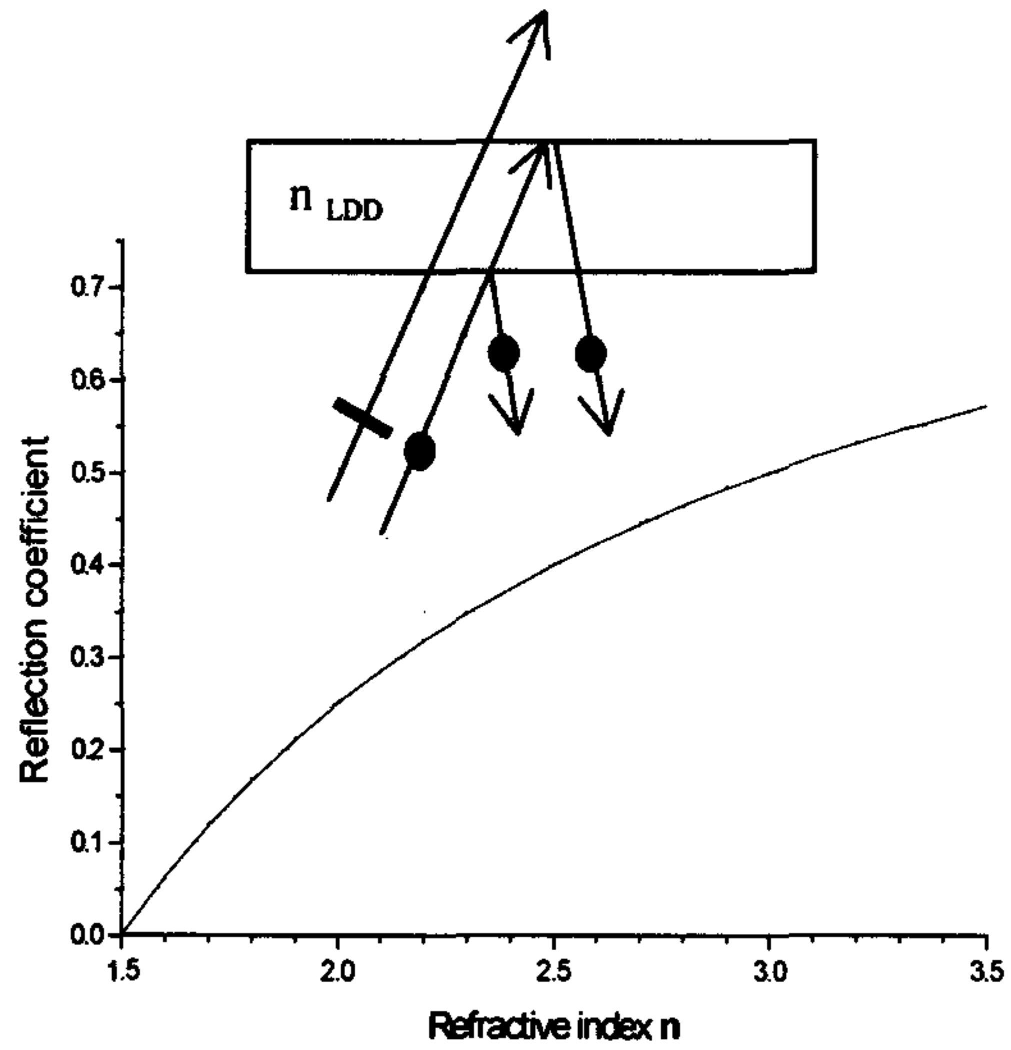



Fig. 5 Reflective polarizer scheme and reflection from each layer vs. LDD refraction index.

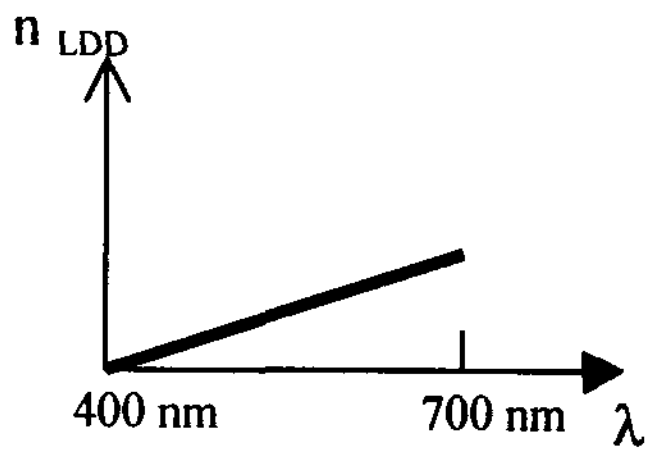



Fig. 6 LDD material refraction index vs. wavelength (abnormal dispersion case).

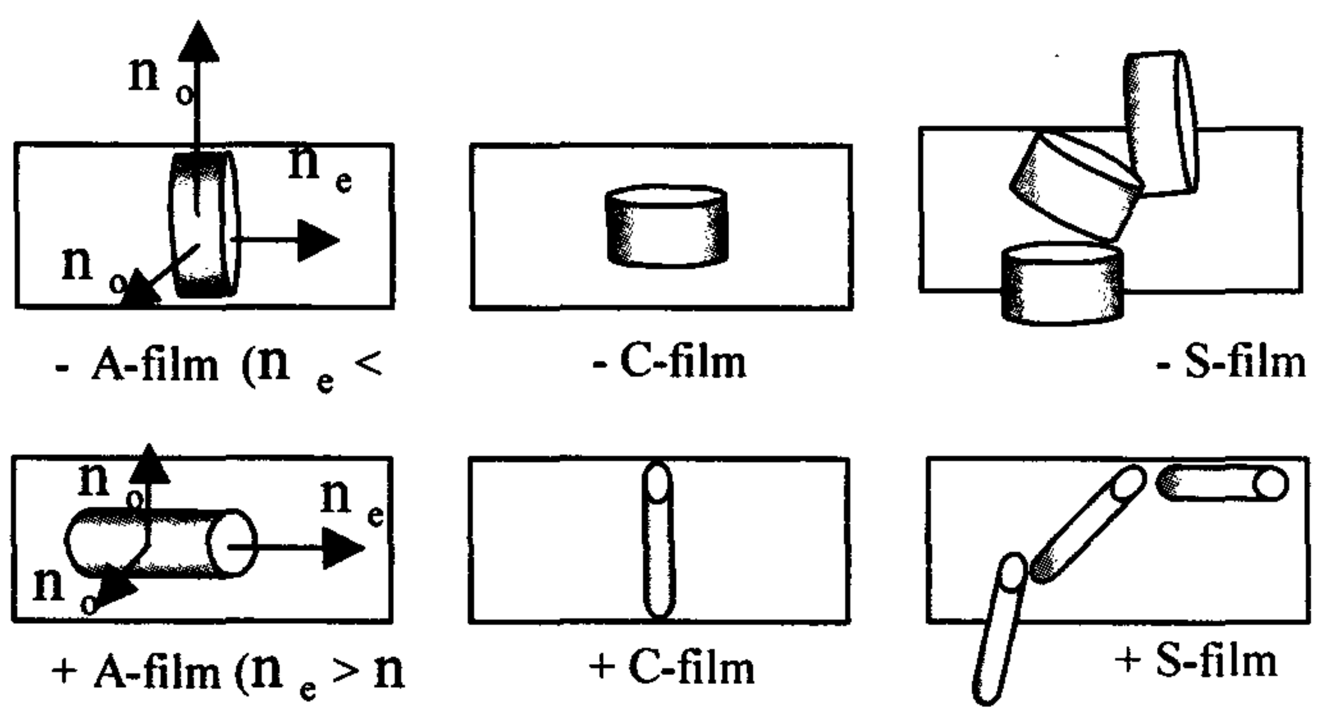



Fig.7 Refractive indices schemes on cross section of various LDD retardation films.