New transparent birefringent material for interference polarizer fabrication

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ABSTRACT

We have developed new clear birefringent material for interference polarizer (I-Polar) fabrication. I-Polar can be used in backlight recycling systems aimed to improve LCD light efficiency and reduce power consumption of the displays. We produced anisotropic films by wet coating of the new material onto a substrate with thickness in the range of 60-90 nm. Such thickness range meets the requirement for optical thickness of layers in the interference polarizer to be equal to the quarter of a wavelength. One birefringent layer of the material coated on glass reflects 12% of polarization orthogonal to the anisotropic film coating direction (refraction index – 1.8) and a stack of 5 layers (3 birefringent layers alternated with 2 isotropic ones, refractive index of the isotropic material is equal to low index of birefringent layer) reflects 31% of the said polarization. We present design of I-polar for typical LCD backlight spectrum.

Keywords: interference polarizer, multilayer reflective polarizer, birefringent layer, LCD backlight

1. INTRODUCTION

LCD is taking over Home TV market. One of the problems of the technology is light efficiency, which is about 7-10 %. About 55% of light produced by backlight source is converted into heat by rear polarizer. Application of reflective polarizers (DBEF) enhances light efficiency of the LCD and shows the direction of future technology development toward non-absorbing, clear polarizers that transmit one polarization and reflect another one and that is further converted into the first polarization and returned into the system. Ultimate solution for backlight efficiency would be elimination of rear polarizer and its replacement by high efficiency interference polarizer that could be as polarization efficient as conventional polarizer and, at the same time, transmit and reflect light without absorption.

There are two main tasks on the way to high efficiency interference polarizers: one is high birefringence of anisotropic layer material and another one is thin coating that is required in order to produce quarter-wavelength layers by wet coating.

We developed material that is highly birefringent - $\Delta n \geq 0.3$ and we produced quarter-wavelength birefringent layers. Present paper reports first results in material development and I-polar prototyping.

Interference polarizer is an optical multilayer interference stack build by the same rules as well known anti-reflection coating used in optics. Major novelty is that I-polar is designed as a multilayer structure of periodically alternating layers of birefringent (1) and isotropic (2) materials: 1,2,1,2,1…, coated in the way to provide maximum interlayer difference of refractive indices in one, in-plane direction and a minimum or no difference in another, perpendicular direction [1].

Principle of operating of the interference polarizer is based on the constructive interference of reflected light by boundary surface of layers having different refractive indices. Interference polarizers rely on the optical interference of light to produce intense light reflection according to the equation [2]:

$$\lambda_m = (2/m) \times (n_1 d_1 + n_2 d_2), \qquad (1)$$

where λ_m is the light wavelength, n_1 and n_2 are the refractive indices of the alternating layers, d_1 and d_2 are the thickness of the corresponding layers, m=1,2,3…is order of reflection (the equation is valid for light incident along the normal to the film surface. For other angles of incidence the equation has to be modified so as to take into account the angle).

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This equation describes optical interference in the y-direction (direction of the maximum refractive indices mismatch), whereas in the orthogonal x-direction ($\Delta n_x = n_{x1} - n_{x2} \approx 0$) optical interference is near zero. As a result the incoming light is separated into two polarizations: P_1 is transmitted in x-direction and P_2 is reflected in y-direction. Using I-polar in combination with light recycling system (quarter plate and mirror, which turns polarization P_2 into P_1, see Fig. 1) can increase degree of polarization of light transmitted through interference polarizer up to 100%.

Commonly used multilayer reflective polarizers (DBEF) are made by polymer co-extrusion with subsequent uniaxial stretching to form in-plane anisotropy [3-5]. Efficiency of reflective system with relatively thick layers is limited. It is expensive if not impossible to produce high efficiency polarizers by extrusion and stretching.

Materials that we develop provide thin (about quarter-wavelength) and high birefringence coatings ($\Delta n \geq 0.3$), which open up opportunities of manufacturing interference polarizers [6-8].

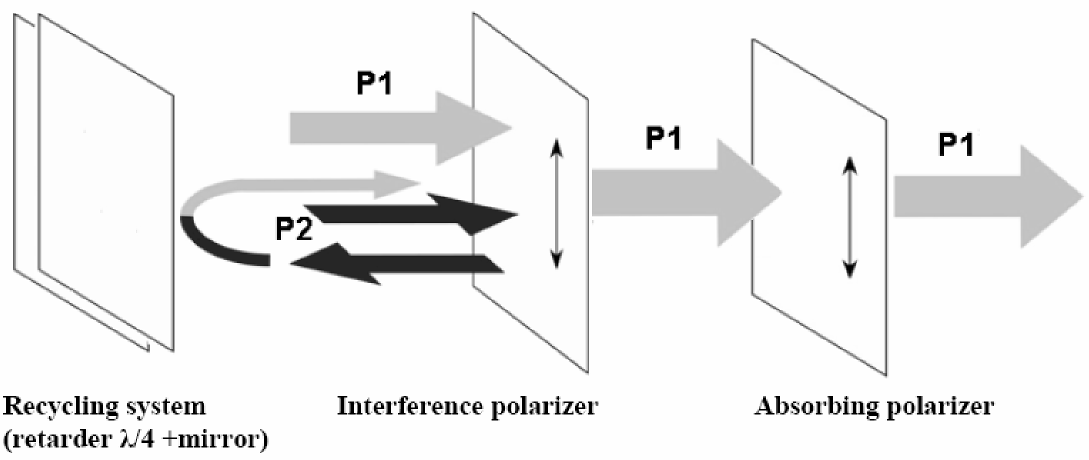


Fig. 1. General principles of interference polarizer functioning and application.

2. MATERIAL

We developed a new transparent birefringent material A02V-G for fabricating I-Polar anisotropic layers. This material belongs to the family of coating materials for TBF™ (thin birefringent film) manufacturing which are based on water-soluble heterocyclic compounds comprising the aromatic molecular core with polar functionalities [8].

The new material meets requirements for interference polarizer:

- clear in visible region (Fig. 2);
- high birefringence with in-plane anisotropy Δn~0.3 (Fig. 3);
- thin coating from low-concentrated solutions to form films with thickness of about 60-90 nm (or quarter-wavelength in the visible region).

Fig. 2 illustrates absorption spectra of the material in UV and visible regions. Strong absorption band in the UV region has sharp left shoulder with zero-absorbance in all useful for LCD area of spectrum. Relatively high extinction in the UV region corresponds to high refractive index in the visible region. Crystal-like anisotropic order in the material built of flat plate-like molecules produces birefringent film with low index in perpendicular direction to the molecular plane.

Coating direction coincides with low index and two other axes have almost equal refraction that corresponds to low order in perpendicular direction to the coating direction plane. We assume that molecules have rotational freedom and are substantially randomly positioned in plane perpendicular to the coating direction.

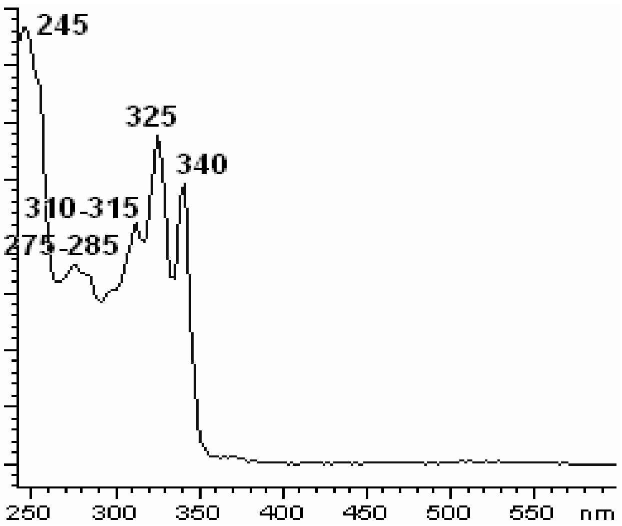


Fig. 2. Absorbance spectrum of A02V-G water solution with concentration C~5·10^{-4}M.

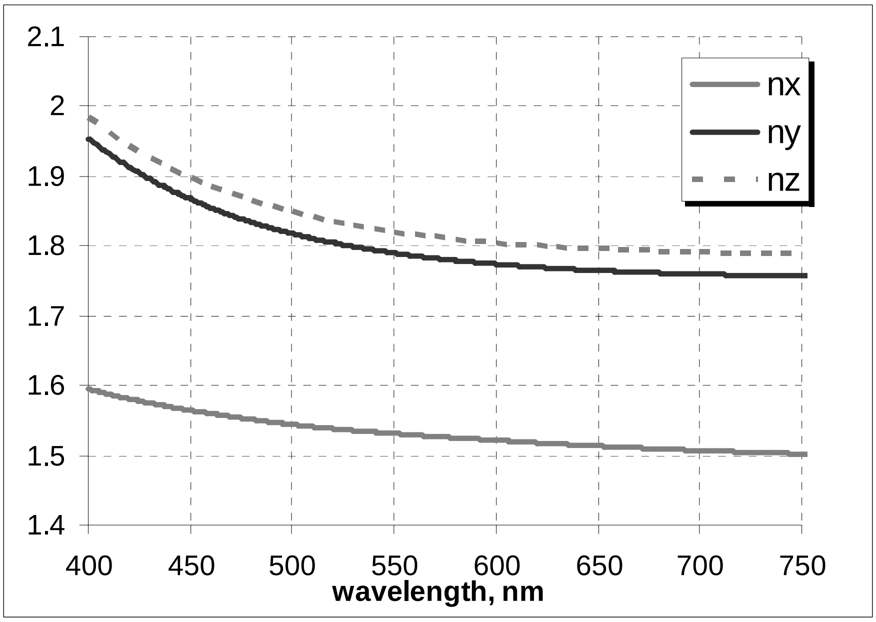


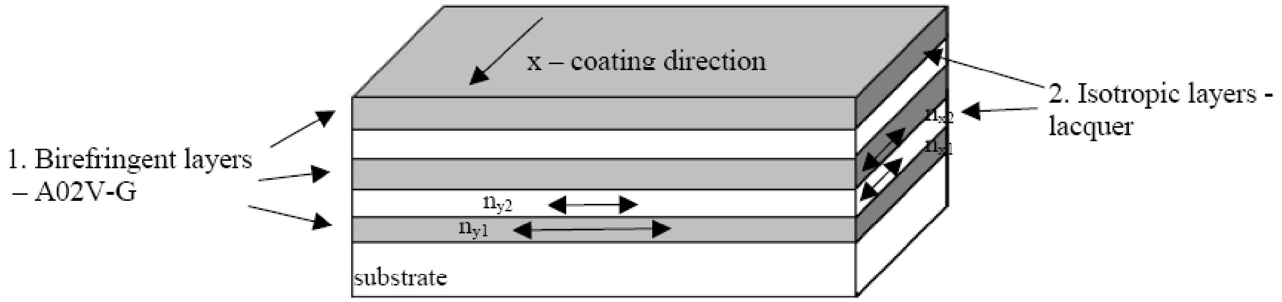
Fig. 3. Refractive indices of TBF™ A02V-G film formed from A02V-G coating material on glass.

3. MULTILAYER INTERFERENCE REFLECTIVE POLARIZER

I-Polar is a structure of alternating isotropic and anisotropic layers. We produced prototype according to the schematic diagram presented in Fig. 4.

A02V-G material was coated onto a glass substrate by micro-grooved Mayer Rod to form TBF™ anisotropic layer. This technique provides alignment of the kinetic units under shear stress. Drying of the wet coating produces resulting thin film. Thickness of the final film is controlled by thickness of the wet layer and solution concentration. It can be set in a range 60-90 nm with good uniformity.

Isotropic layer was produced by spin-coating of clear acrylic UV-curable lacquer. We chose a particular lacquer material to match refractive index of isotropic film to the minimum in-plane index of the birefringent material (Fig. 4). By varying spin-coater angular velocity and lacquer concentration in the mixture with solvent we adjusted conditions to fit the thickness of the lacquer layer to the desirable value.



$$n_{y1} > n_{x1}$$
$$n_{y2} \approx n_{x2} \approx n_{x1}$$

Fig. 4. Scheme of 5-layer I-Polar film.

Thicknesses of both birefringent and isotropic layers were adjusted to provide a maximum reflectance at 530 nm: 74 nm thick birefringent layer (optical thickness is equal to ¼ λ), 260 nm thick isotropic layer (optical thickness corresponds to ¾ λ).

Multilayer stack produced on a glass substrate comprised 5 layers: 3 birefringent and 2 isotropic layers. Computer simulated and experimental reflectance spectra of the produced multilayer film are presented in Fig. 5.

We believe that discrepancies between our simulation and experiment are produced by defects in anisotropic films that are created by the Mayer Rod coating used in these experiments. Grooves on Mayer rod create specific periodic structures in birefringent film that make it uneven and reduce resulting birefringence. This type of defects would not be present in other coating techniques, for example slot die.

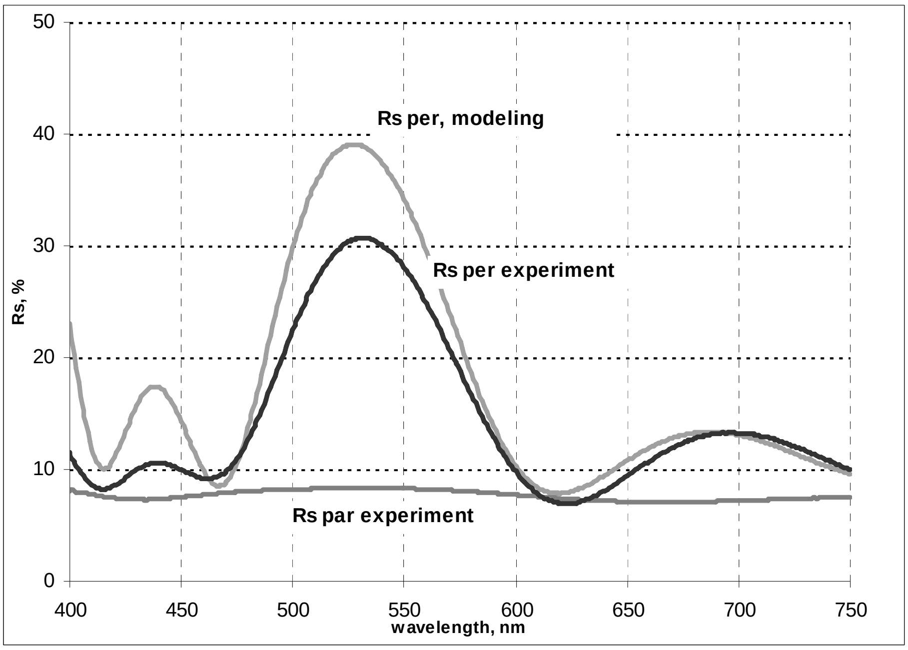


Fig. 5. Computer simulated and experimental reflectance spectra of 5-layer film (12 deg incidence, S-polarization).

Reflectance spectrum of experimental prototype corresponds to typical interference pattern with satellite maxima next to major reflectance peak.

4. DISCUSSION

The structure that was produced in the experiment is optimized to provide a peak reflectance at 530 nm. At the same time thickness tuning according to condition (1) opens up the possibility to tailor structure so as to reflect light in any desirable wavelength region.

In Fig. 6 we present an I-polar structure developed for typical backlight source (CCFT spectrum is given at the diagram) as an example of multilayer coating technology application. The designed structure is made of three cavities tailored for different wavelengths (29 layers total). Simulated reflectance of the structure amounts to 60-65% for one polarization (P_2 in Fig. 1) at the selected wavelength range (Fig. 6), whereas the reflectance of P_1 remains within 8%. Calculations predicts a portion of P_1 in the transmitted light equal to about 77% (taking into account an ideal recycling system with wavelength independent quarter plate), which corresponds to about 54% total brightness enhancement.

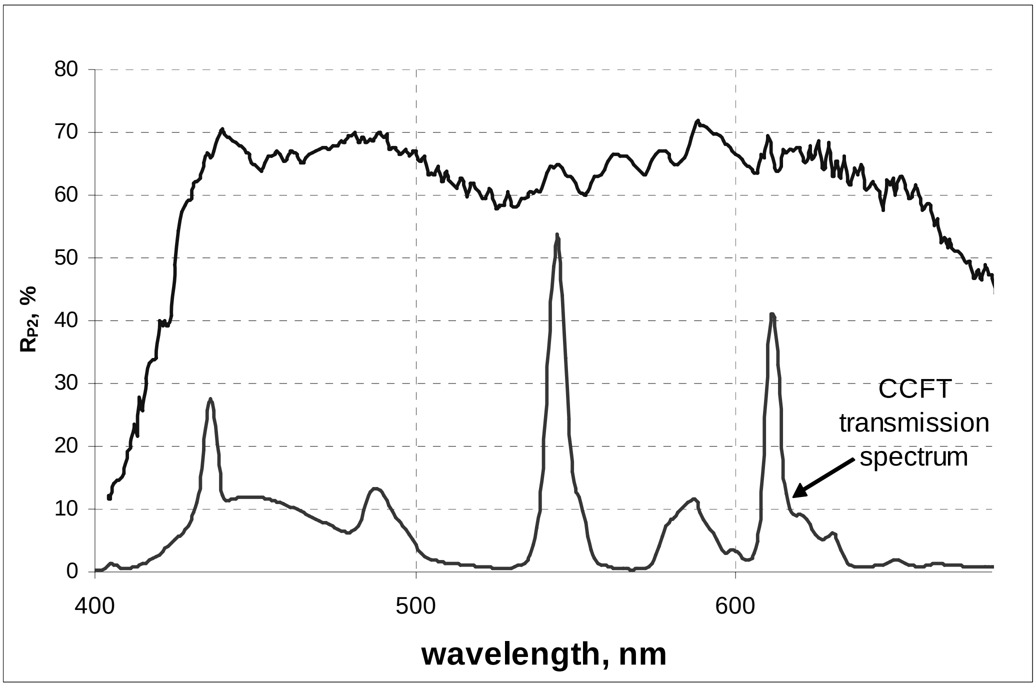


Fig. 6. Reflectance of multilayer film (computer simulation).

5. CONCLUSIONS

We developed material with 0.3 birefringence and coating thickness about ¼ wavelength of visible light. With this material, we produced prototype of I-polar (interference polarizer) with reflectance characteristics similar to some of commercially available reflective polarizers (DBEF).

Developing the I-Polar films into the energy saving replacement for the back polarizer in an LCD would take efforts in two major directions. One – is the development of materials with large Δn (such as 0.6, 0.8, etc.). Another – is developing coating technology to allow wet coating of a larger number of layers with high yield. Perhaps that could be done using multiple layer coatings in a single pass.

REFERENCES

1. Polarized Interference Recycling Backlight Module And Liquid Crystal Display Incorporating The Same, US 2005/0195340 (2005).
2. T. Alfrey, E.F. Gurnee, W.J. Schrenk, “Physical Optics of Iridescent Multilayered Plastic Films”, *Polymer Engineering and Science* 9, 400-404 (1969).
3. Multilayer Light Polarizer, US 3610729 (1971).
4. Multilayered optical film, WO 9517303 (1995).
5. Birefringent interference polarization, US 6583930 (2003).
6. P. Lazarev, V. Nazarov, N. Ovchinnikova, S. Remizov, “Printed Optical Components for Liquid Crystal Displays”, *12th International Symposium, Advanced Display Technologies: Basic Studies of Problems in Information Display (FLOWERS’2003),* August 25-28, p.186-189 (2003).
7. Y. Bobrov, O. Kuchenkova, M. Kouznetsov, P. Lazarev, A. Manko, V. Nazarov, N. Ovchinnikova, M. Paukshto, P. Protsenko and S. Remizov, “LCD applications of thin-crystal-film polarizers”, *Journal of the SID,* 12/2, pp. 125-133 (2004).
8. Patents pending.