P-113: Materials for Light Efficient LCD

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Abstract

The way to increase efficiency of modern LCD is to remove the absorbing optical components: color filter and dichroic polarizer. Non-absorbing polarizer together with sub-millisecond fast LC mode working in field-sequential RGB mode are the keys to future LCD.

1. Introduction

Home TV market created a great demand for liquid crystal display (LCD) panels capable of displaying video images with improved contrast and increased brightness.

In general, conventional color LCD panels have essentially the same basic construction as Home TV LCD. Each LCD panel comprises the following main components: a backlight structure for producing a plane of uniform lighting intensity; front and rear polarizers; an electrically-addressable array of control elements producing modulation of the light intensity; and an array of color filters located in the proximity of the array of the modulating elements.

Color filters produce spectral filtering of the modulated light in order to form a color image. Because of more than 2/3 of the light energy is absorbed by color filters and, in addition, at least half of the light is lost inside the rear polarizer the output light efficiency of the color LCD panel is very low. As a result of these factors, the light transmission efficiency of conventional color LCD panels without the double brightness enhancing films (DBEF) is typically not greater than 5-7%. With use of the DBEF films it reaches up to 10-14% [1]. Consequently, up to 86-95% of the light produced by the backlight structure is converted into heat across the LCD panel. Heat dissipation is a major problem in a large area LCD and it is growing more severe with increase in size of the panel.

Examples of applications requiring improved displays include mobile communication and computing systems, high-performance workstation monitors and notebooks, laptops and other computers. It is impossible to produce high-brightness images using conventional color LCD panels in neither direct nor projection display systems without using ultra-high intensity backlight sources, which require high supplied power, special cooling system with air fans and produce increasing amounts of heat. LCD industry needs new solutions and one of them is elimination of the dichroic polarizers (rear polarizer) and the color filters. This approach has been developed in Home TV LCD Light Efficiency Enhancement Program pioneered by Crysoptix KK [2-4].

Color filters can be eliminated by using high efficiency RGB Field Sequential Backlight (RGB FSB) [5]. The losses of efficiency caused by absorbing rear polarizer can be eliminated if it is replaced by reflective polarizer, which allows recirculation of the light energy. In special LCD designs an additional increase of efficiency can be achieved by a similar replacement of the front polarizer as well.

In this paper we describe materials for creating non-absorbing optical polarizers for LCD based on constructive interference.

2. Non-absorbing polarizers

Constructive interference was widely used for high efficiency components in optical industry for randomly polarized light. In our case the constructive interference is sensitive to the light polarization state because of optical anisotropy of the used materials.

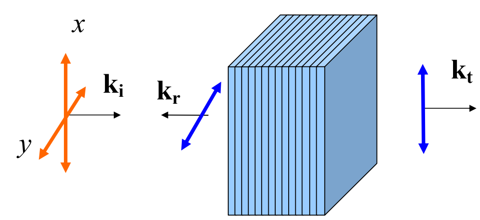

Figure 1. Schematic view of the non-absorbing polarizer

In order to create efficient interference components which can serve as a replacement of currently used dichroic polarizer we need a technology, which can produce multilayer films with high anisotropy and quarter wave optical thickness of each layer, which corresponds to physical thickness of 80 nm for wavelength of 550 nm (green light).

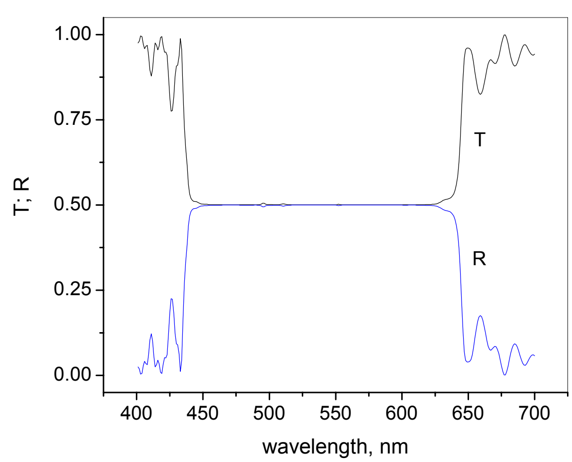

Figure 2. Transmission (T) and Reflection (R) spectra for non-absorbing polarizer consisting of three blocks of layers

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Such multilayer structures behave as one-dimensional photonic crystals, with photonic band gap (PBG) for one of the light polarization states. Inside the PBG spectral range the propagation of photons of proper polarization is forbidden, so these photons are reflected. The other photons, which have the orthogonal polarization, are transmitted as shown in Figure 1.

Thus the PBG structure works as the polarizer, which we name as *photonic non-absorbing polarizer*. Figure 2 illustrates an example of transmission and reflection spectra for the non-absorbing polarizer. In this example the non-absorbing polarizer consists of three blocks of multilayers. Each of the blocks has its own PBG adjusted for blue, green and red spectral range.

2.1. Optical materials for non-absorbing polarizer

The interference polarizer can be created using Crysoptix materials [2] by producing alternating individual layers of the multilayer structure: negative A-plate material for in-plane anisotropic layers and negative C-plate material for in-plane isotropic layers.

2.1.1. Negative A-plate retarder

We developed a new transparent birefringent material A02V-G for fabricating anisotropic layers for negative A-type plate [6]. This material belongs to the family of coating materials for TBF™ (thin birefringent film) manufacturing. It is based on water-soluble heterocyclic compounds comprising the aromatic molecular core with polar functionalities.

The new water-based coating material meets requirements for multilayer films:

- zero-absorbance in visible region (Figure 3);
- high birefringence of the coated film with in-plane anisotropy $\Delta n \sim 0.32$ (Figure 4);
- capability to form a thin coating (with dry film thickness of about 60-90 nm or quarter-wavelength in the visible region) from low-concentrated solutions.

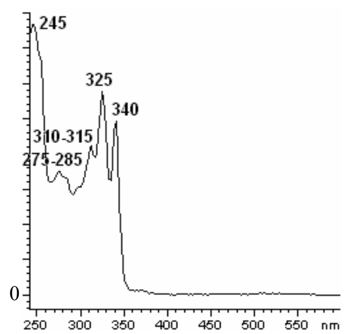

Figure 3. Absorption spectrum for A02V-G coating material

Figure 3 illustrates absorption spectra of the coating material in UV and visible regions. Strong absorption band is located in the UV region. In all useful for LCD visible range of spectrum the absorption is negligible. Relatively high extinction in the UV region results in high refractive index in the visible region. Crystal-like order in the material built of anisotropic plate-like molecules produces a birefringent film. Here the coating direction corresponds to the lowest index, while for the two other axes the refraction indices are equal. The last is explained by random distribution of the molecules orientation in the plane perpendicular to the coating direction.

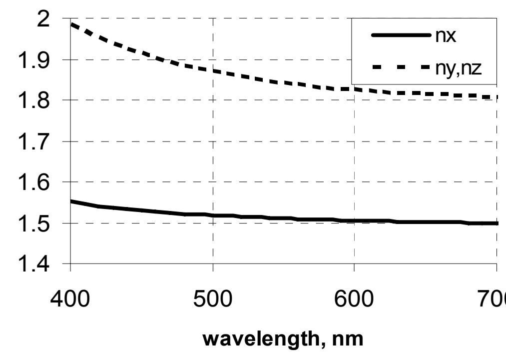

Figure 4. Spectra of principal refractive indices for negative A-plate TBF™ retarder based on A02V-G

The spectra of principal refractive indices of the resulting birefringent film are shown in Figure 4. At a wavelength of 550 nm they are nx = 1.51, ny = nz = 1.83.

2.1.2. Negative C-plate retarder

We developed a new transparent birefringent material for fabricating anisotropic layers of negative C-plate CN-LT-2000 TBF™ coatable from aqueous solution onto plastic and glass substrates [6]. New negative C-plate possesses high out-of-plane birefringence, which results in thinner retardation film. The TBF™ technology allows production of films with required retardation by virtue of film thickness control.

New negative C-plate material is based on block copolymer of sulfonated benzidine phthalamide derivatives. The molecules have a rigid core and stick-like shape. Under drying of a wet film formed from a coating solution on a substrate, a solvent (water) evaporates and the molecules arrange in the plane of the film with their long axes parallel to the substrate plane but without any preferential direction.

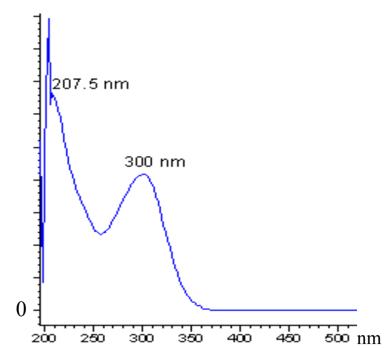

Figure 5. Absorption spectrum for negative C-plate CN-LT-2000 TBF™ coating material

The CN-LT-2000 TBF™ coating material is highly transparent and colorless (Figure 5). The spectra of principal refractive indices of CN-LT-2000 TBF™ retarder are shown in Figure 6. The principal refractive indices at the wavelength of 550 nm are nx = ny = 1.71, nz = 1.57 and out-of-plane birefringence is Δn = 0.14.

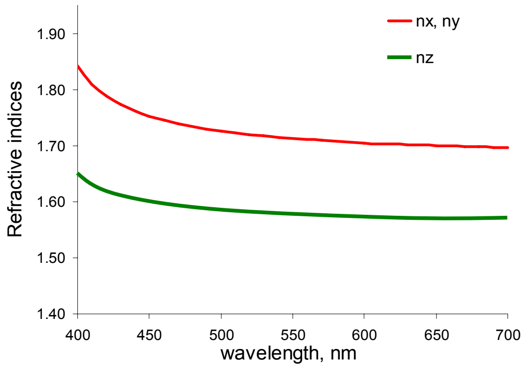

Figure 6. Spectra of principal refractive indices for negative C-plate TBF™ retarder

The retarder is coatable from water solutions. It does not require any special operations during the drying step, and birefringence of the film is not influenced by drying conditions. After drying the films should be post-treated in order to provide insolubility in water. The films exhibit high adhesion to glass and plastic substrates, high temperature stability and environmental durability.

2.2. Coating technology

To maintain economic competitiveness of such product the manufacturing process should be compatible with roll-to-roll methods. Such opportunity is provided by printable TBF™ materials which form anisotropic films. Moreover, such materials should have concentration of liquid solution in the range of 1-3 % of solids – in order to be compatible with a typical slot die or reverse roll coating methods that produces 5-10 micron thick (wet layer) coating. Hence, liquid material must have concentration of about 2%, in order to produce an 80 nm thick dry layer.

An alternative to roll-to-roll coating method can be multi-manifold slot die [7]. Described multilayer coating approach is originated from photofilm fabrication. By developing a special slot die head one can make desired non-absorbing polarizer coating at single coating round. Figure 7 illustrates how different liquids are pumped through designated slots and form multilayer structure during single step.

We present lyotropic liquid crystalline and gel materials with ability to produce films with an optical anisotropy in a range of 0.14-0.32 and required quarter wave thickness.

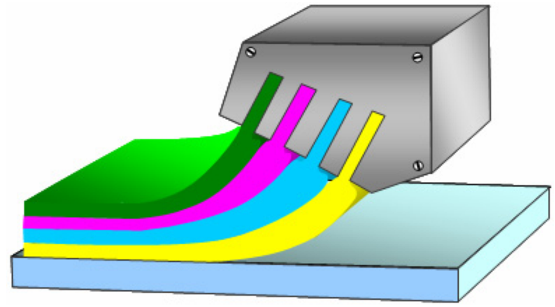

Figure 7. Multi-manifold slot die head

3. Conclusions

Light efficiency of LCD requires elimination of all light absorbing components. Color filters can be eliminated by field-sequential RGB backlight. Dichroic polarizers will be substituted by high-efficiency interference polarizers in backlight and in front polarizer analyzer. Interference polarizers comprise alternating multilayer structure of isotropic and anisotropic materials deposited in thin layers.

The use of non-absorbing interference polarizer together with sub-millisecond fast LC mode working in field-sequential RGB mode will result in enhancement of LCD light efficiency.

Materials developed by Crysoptix and presented in this paper allow manufacturing interference polarizers by roll-to-roll printing, therefore providing the technological foundation to implement the Home TV LCD Light Efficiency Enhancement Program.

4. References

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