P-81: Twisted Nematic Reflective Display with Internal Wire Grid Polarizer

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Abstract

We studied the optical performance of reflective wire grid polarizer designed for visible light. The polarizer reflects E-polarization and transmits H-polarization with low losses. When used in a twisted nematic (TN) device as a back polarizer it enhances the brightness and provides high contrast ratio at wide viewing angles. By placing the wire grid polarizer within the cell, viewing parallax is eliminated. The polarizer can also be used as the rear electrode.

1. Introduction

The market demands of handheld computing and telecommunication products stimulate the development of new technologies for high performance reflective liquid crystal displays. The first generation of reflective displays utilized a twisted nematic cell placed between crossed dichroic polarizers with aluminum reflector on back. However, brightness of this device is limited to R_{max} ~27%. One of the solutions for brightness enhancement is the use of a reflective polarizer. A grid of thin conducting wires is extensively used as infrared and radio wave polarizers [1]. However, to be useful in the visible light region, the period of the grating should be much less than the wavelength of light. The first wire grid polarizer for visible light was recently introduced by Moxtek. [2]. Recent technological progress allows manufacturing of large area gratings with periods on the order of 100 nm, and even smaller, that can be applicable to polarizing beam splitters and birefringence films. The grating with that small period does not show any diffraction behavior for visible light and thus can be treated as an effective birefringent medium with anisotropic absorption. The first considerations of the applicability of the effective medium theory to the wire grids were expressed in the works of A. Yariv and P. Yeh [3-5]. The authors suggested that a layered medium with period, Λ, that consists of alternating layers of different homogeneous and isotropic substances behaves as a uniaxial birefringent medium with ordinary and extraordinary indices, n_0 and n_e, given by [3-5]

$$n_0^2 = \frac{a}{\Lambda} n_1^2 + \frac{b}{\Lambda} n_2^2 \qquad (1)$$

$$\frac{1}{n_e^2} = \frac{a}{\Lambda}\frac{1}{n_1^2} + \frac{b}{\Lambda}\frac{1}{n_2^2} \qquad (2)$$

where n_1 is the complex refractive indices for the metallic layers, n_2 is the refractive index of the dielectric medium, a is the wire width, and $\Lambda = a + b$ is the period of the structure. The wire grid can be presented as thin strips of such medium consisting of alternating metal and dielectric material. In the case when the wire grids are made of perfect conductors and the dielectric spaces are made of perfect insulators, incident radiation with the electric field vector parallel to the wire grids interacts with the medium that has a refractive index mostly determined by the metallic layers, and is reflected. For incident radiation with dielectric vector perpendicular to the wire grids, the polarizer behaves as a perfect dielectric layer, and mostly transmits. The effective medium described above provides the main features of the optical behavior of the wire grid. In our work we applied this approach to estimate the absorption and refractive indices of the effective medium that adequately represents Moxtek's polarizers. We have shown that the medium with estimated parameters can be incorporated in liquid crystal device modeling based on Berrreman's 4x4 matrix approach [6] as an accurate polarizer representation. We also present comparisons between modeled and measured data on optical performance of wire-grid polarizers designed for the visible light spectrum and show their application for liquid crystal devices**.**

2. Measurement setup

The measurements of the reflected luminance were performed with the setup shown in figure 1. We adjusted the incidence angle of light by moving both the camera and the lamp to obtain the desired polar angle and then rotated the display in the azimuthal plane. The display brightness was characterized by the reflected luminance compared to the luminance of the light source. Iso-luminance transmission curves for a polarizer stack and iso-contrast curves for TN devices were performed using the same instruments however, the luminance data were collected in transmission mode.

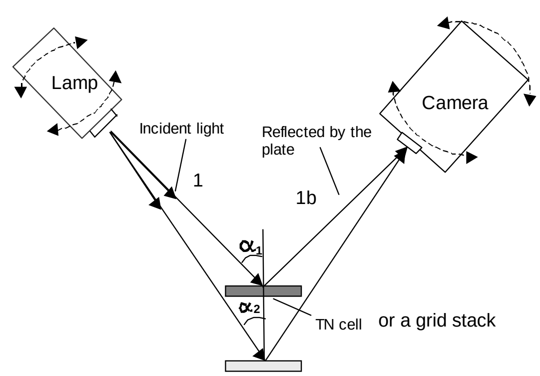


Figure 1. Experimental setup for measurements of specular reflections from reflective devices.

3. Optical performance of grid stacks

Figure 2 presents the measured reflectance from a stack of two crossed wire grids. Two wire grids have very high reflectivity exceeding 78% that is close to the reflectivity of an aluminum mirror. Figure 3 shows the measured transmission of two crossed grids. It is evident that two crossed wire grid polarizers are almost as effective as conventional dichroic polarizers. These measurements were performed in order to find parameters of an effective medium that would give quantitative agreement with experimentally measured reflectivity and transmission of the grids over a wide range of incidence angles and within the visible spectrum. We treated a wire grid polarizer as a birefringent medium with anisotropic absorption and initially estimated the refractive and absorption indices by using (1)-(2). However, the estimated indices would provide only qualitative agreement with experiment. In order to provide the quantitative agreement with experimental data, we measured and modeled the transmission of stacks of crossed grids at different spectral regions of visible light.

To calculate transmission and reflectivity of polarized light from a grid stack we used the approach based on Berreman's 4X4 matrix method. The results of the calculations were reflected and transmitted luminance at a specified viewing direction, determined by a pair of polar and azimuthal angles. The absorption coefficients $k_e(\lambda)$ were varied in the range of visible light and were chosen as fitting parameters. The other fitting parameter was the thickness of the effective medium, *d*. At the same time, the medium with chosen indices must have the same thickness for all wavelengths.

The actual grid reflects light better in the red than in the blue. This effect was modeled using smaller absorption coefficients for the blue end of the spectrum than for the red. We found that the reflectivity of the stack primarily depends on the absolute value of k_e: the higher absorption coefficient resulting in higher reflectivity. On the other hand, transmission of the stack increases

Reflection, %

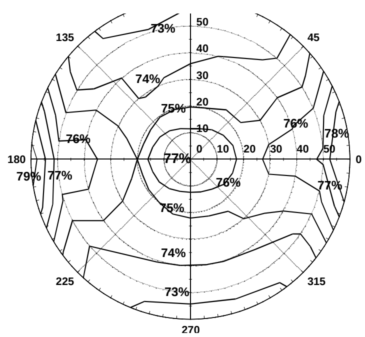


Figure 2. Measured reflectivity of two crossed wire grids, white light.

Reflection, %

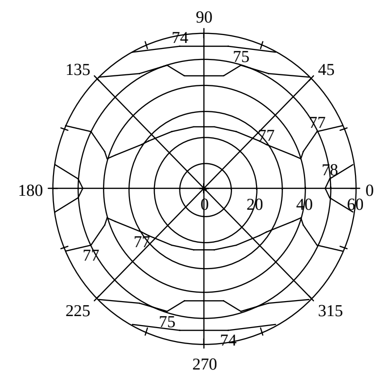


Figure 4. Modeled reflectivity of two crossed wire grids, white light

Transmission, %

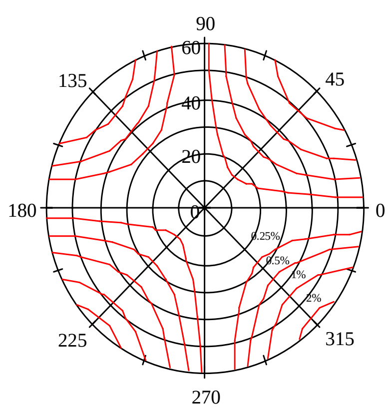
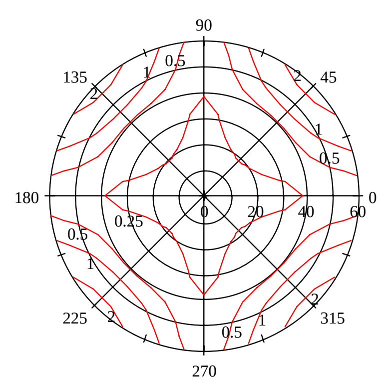


Figure 3. Measured transmission of white light by a stack of two crossed grids.

Transmission, %



. Modeled transmission of white light by a stack rossed grids.

with a de the effective medium thickness, *d*.

We found that the effective medium with the thickness *d*=0.043 microns and indices presented in Table 1 adequately describes the performance of the grid in optically dense glycerin.

Table 1. Indices of refraction and absorption for uniaxial birefringent absorptive medium used in modeling of wire grid polarizers.

Wavelemgth, nm	no	ko	ne	ke
400	1.5	0.1	1.48	4.1
450	1.5	0.1	1.48	4.45
500	1.5	0.1	1.48	4.7
550	1.5	0.1	1.48	5
600	1.5	0.1	1.48	5.9
650	1.5	0.1	1.48	6.4
700	1.5	0.1	1.48	6.8

Figure 4 shows modeled percent reflection for the crossed grid stack. Figure 5 presents modeled curves for percent transmission of white light. Comparison of measured and modeled data demonstrate that the uniaxial birefringent medium with anisotropic absorption can be used as an adequate representation of wire grid polarizers.

4. Measurement and modeling of the direct view reflective device with wire-grid polarizers

In order to study the optical performance of the grids for liquid crystal displays we modeled and measured the optical performance of TN reflective devices that had a wire-grid polarizer on the back and a dichroic polarizer on the front. The device was tested in reflection mode. The basic element of the device was a liquid crystal cell with 90^o twisted director configuration. The 5.1-micron thick cell was filled with nematic fluid ZLI4792 (manufactured by Merck). A sample of a wire grid on glass substrate was used as a back substrate for the TN cell. Thus, the grid polarizer served as an internal polarizer and back electrode. In some cases, the back alignment was also provided by the wire grid. By placing the polarizer inside the LC cell, we avoided parallax in the reflection device. The dichroic polarizer used as a front polarizer had an anti-reflection coating. In order to employ normally white mode in reflection, the front polarizer was attached with its transmission direction perpendicular to the grid.

Figures 6 and 7 show measured and modeled iso-contrast curves for a reflective display driven between 0 and 6 V. The figures show a remarkable agreement between the measured and modeled data.

We also built and studied TN devices with an aluminum mirror and a dichroic polarizer on the back. The optical performance of the latter device was compared to the device with the wire grid on back. We found that the displays have similar iso-contrast characteristics. However, the device with a dichroic polarizer and a mirror on back has a compared maximum reflectivity of 27%, which is about 10% lower than for the device with wire-grid polarizer.

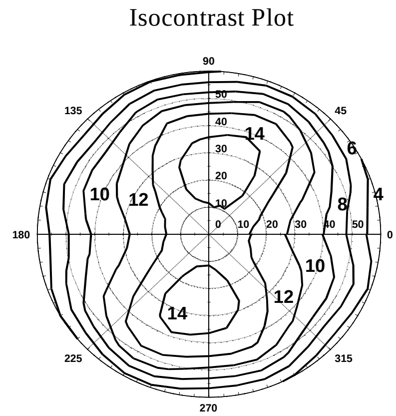


Figure 6. Measured iso-contrast curves for reflective TN device with wire grid polarizers on back.

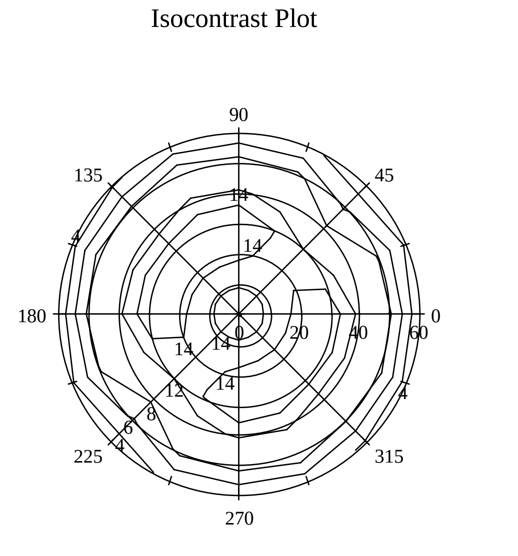


Figure 7. Modeled iso-contrast curves for reflective TN device with wire grid polarizers on back.

5. Conclusions

The conducted research shows that the optical performance of Moxtek's wire-grid polarizer can be adequately described using an effective medium with anisotropic absorption. The medium possesses high transmission for light polarized in the direction perpendicular to the wires and high reflectivity for light polarized in the direction parallel to the wires. In order to find the parameters of an effective medium that gives quantitative agreement with experimentally measured reflectivity and transmission of the grids over a wide range of incidence angles and within the visible spectrum, we measured and modeled the reflectivity and transmission of two crossed and two parallel grids when the incident light was not polarized. The effective medium with the thickness of d=0.043 microns and n_o=1.5, n_e=1.48, k_o=0.1 and k_e=4.1÷6.8 in the wavelength range λ=400÷700 nm provided good agreement of measured and modeled data for a wire grid in an optically dense medium. The estimated parameters of the grid polarizer were used for modeling of a TN reflection device. The modeled data are in good agreement with the measurements of the actual device that employed one grid polarizer and one dichroic polarizer. Twisted nematic reflective devices with wire-grid polarizers provide high contrast and wide viewing angle performance, brightness enhancement and elimination of viewing parallax. Wire grids placed inside the active liquid crystal cell may serve simultaneously as polarizers, alignment layers and back electrode.

6. Acknowledgments

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