Fringing Field Effect and the measurement of the subpixel Jones matrices of an LCD

Christian Lingel, Christian Thiel, Tobias Haist, Wolfgang Osten
Institut für Technische Optik, Universität Stuttgart
mailto:christian.lingel@ito.uni-stuttgart.de

We present a method for measuring the subpixel Jones matrix of a liquid crystal on silicon (LCoS) display, which is used as phase only spatial light modulator (SLM). Using the measurement results we examine the fringing field effect of such modulators and show a simulation model of the SLM which takes the crosstalk between the pixels into account. We also show that there is a direction dependence of the fringing field effect.

1 Introduction

In some optical systems it is desirable to vary the light distribution among the optical path without mechanical change of the setup. Spatial light modulators (SLMs) are often employed for that purpose. Various types are known, such as digital micromirror devices (DMDs), liquid crystal SLMs or acousto-optical modulators (AOMs). Efficient phase modulation with a large space-bandwidth product is typically achieved using liquid crystal displays (LCDs). The pixelated phase modulation in the LCD is achieved by changing the refractive index of the liquid crystal layer by modifying the orientation of the liquid crystal molecules.

In this work we use a PLUTO-VIS spatial phase modulator from Holoeye Photonics AG [1]. The modulator is a high-definition LCoS display with 1920 $\times$ 1080 pixels, a pixel pitch of 8 μm and a fill factor of 87$\%$.

However, several factors limit the usability of LCDs in holography [2] and therefore it is crucial to measure these effects [3] and optimize the addressing [4]. One of the main limitations is the fringing field effect. Our aim is to optimize the diffraction efficiency by considering the fringing field effect already during the calculation of the hologram. Therefore we need a simulation model which is able to simulate this effect. Here we present a model which is based on the measurement of the subpixel Jones matrices of the LCD.

2 Fringing Field Effect

The fringing field effect is the crosstalk between neighboring pixels which arises if different gray values respectively phase values are written in the adjacent pixels [5]. This results in a blurring effect of the desired sharp edges between the pixels. The above mentioned modification of the orientation of the LC molecules in a pixel is induced by the electric field which controls the pixel. Since the electric field is not limited to the area of one pixel, the molecules of a neighboring pixel are influenced by the electric field of the pixel. As consequence the diffraction efficiency is influenced by this effect, see section 4.1.

3 Measuring the subpixel Jones matrices

The Jones matrix $\underline{\underline{J}}$ describes the effect of an optical element, e.g. a polarizer, on the polarization [6]. By factoring out a common phasefactor $a_{pf} = \exp(i\phi_{xx})$ the Jones matrix can be written as

$$\underline{\underline{J}} = a_{pf}\underline{\underline{J_{pr}}} \tag{1}$$

with the phase reduced Jones matrix

$$\underline{\underline{J_{pr}}} = \begin{bmatrix} A_{xx} & A_{xy}e^{i(\phi_{xy}-\phi_{xx})} \\ A_{yx}e^{i(\phi_{yx}-\phi_{xx})} & A_{yy}e^{i(\phi_{yy}-\phi_{xx})} \end{bmatrix} \tag{2}$$

For determining the full Jones matrix we need two setups. The first one to get the phase-reduced Jones matrix and the second one to measure the phase-factor. In the following these setups and the according measurement procedures are described, that will yield us the Jones matrix.

For the phase-reduced Jones matrix we use the optical setup depicted in Fig 1. During the measurement procedure we change the orientation of the two polarizers to 3 different angles (0°,45°,90°). Using all combinations we end up with 9 different configurations. Then we perform additional measurements using a quarter wave plate in front of the second polarizer for 2 different orientations (0°,45°). Finally, we have 15 different microscopic images of the LCD with different intensities dependent on the used configuration. So we can use the subpixel intensities for our calculations.

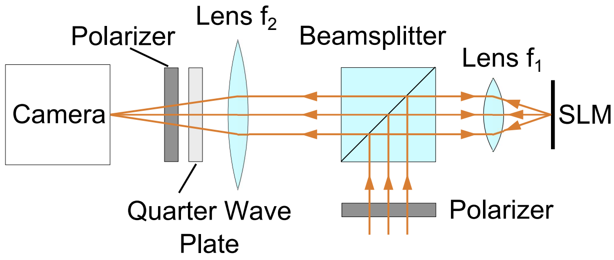

***Fig. 1** Optical setup for measuring the phase-reduced Jones matrix.*

Next, we calculate the system with the Jones formalism and use an arbitrary Jones matrix for the SLM. As a result we get 15 simulated intensities which are dependent on the Jones matrix of the SLM. We build a merit function which is calculated as the mean square error between the 15 measured and the 15 simulated intensities. Using a simulated annealing algorithm we minimize the merit function by adjusting the arbitrary Jones matrix. After the optimization we obtain the phase-reduced Jones matrix which corresponds to the 15 measured intensities. In order to find the phasefactor which is necessary for the full Jones matrix, we change the optical setup to an interferometric one, see Fig. 2. If we then write two different gray values in the LCD and adjust the two polarizers parallel we are able to measure the dynamic phase difference between the two gray values. By image processing of the interferometric image we get a phase profile of a phase step between two different phases, see Fig. 3. From this we obtain the phasefactor in the subpixel range for completing the Jones matrix.

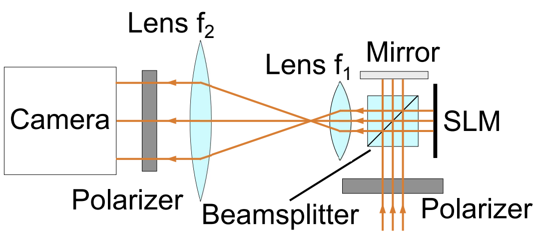

***Fig. 2** Optical setup for measuring the phasefactor.*

4 Simulation Model

For the simulation we measure the subpixel Jones matrices of different (horizontal and vertical) gray value steps in the fringing field area and store the results in a lookup table. With this lookup table we are able to simulate horizontal and vertical structures (gratings). During the simulation we compare the gray value change in the grating with our lookup table and use the respective Jones matrix for each subpixel for simulating the effect of the LCD on the phase and polarization. Therefore, we are able to simulate the reconstructed intensity distribution and can calculate the diffraction efficiency.

4.1 Results

If we compare the results for a horizontal and a vertical blazed grating (fill factor SLM: 79%; pixel periode: 10) we recognize a difference in the diffraction efficiency. The simulated diffraction efficiency, calculated as the ratio of the intensity of the first diffraction order to the overall intensity of the diffraction image, is approximately 55% for the horizontal grating and 60% for the vertical grating. This difference arises because of the different magnitudes of the fringing field effect in both directions.

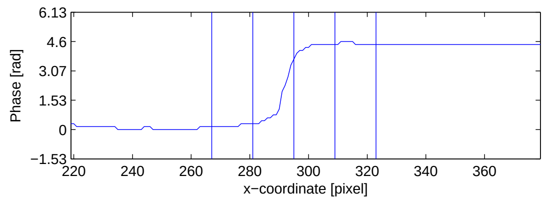

***Fig. 3** Phase profile of a phase step. The horizontal lines in the middle describe the pixelgrid.*

5 Conclusion

We presented a way of measuring the subpixel Jones matrices of an LCD and use the results for a simulation model. With this model we are able to simulate horizontal and vertical gratings and we have shown that there is a difference in diffraction efficiency caused by the orientation dependent fringing field effect.

6 Acknowledgments

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