# Numerical Modeling for the Beam Steering Systems based on the LC Polarization Grating

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Keywords: simulation, gratings, diffraction, polarization grating

**ABSTRACT**

*We demonstrated the evaluation of the beam steering system including liquid crystal polarization grating (LCPG) by numerical modeling. The optical response is calculated by rigorous coupled-wave analysis which is best suited for grating analysis. We show the validity of the numerical simulation for designing LCPG devices.*

## 1 Introduction

Liquid crystal polarization grating (LCPG) is a unique technology to control light direction based on optical diffraction [1]. Recently, many works have been reported to be applied to beam steering devices [2]. The optical performance such as the transmittance or the diffraction angle can be optimized by considering the periodicity of the director in the cell, incident polarized light, etc. However, the mechanism is fairly complicated. The conventional approaches just derived from a simple analytical model are insufficient to design them precisely and efficiently. Fortunately, some algorithms based on the rigorous coupled-wave analysis (RCWA) method [3] have been proposed to estimate such performance rapidly and precisely [4].

In this study, we demonstrate that such a numerical approach is indispensable for creating novel LCPG devices through modeling a beam steering system as an example.

## 2 Simulation

Our model is shown in Figure 1. The model consists of double layers of VA LC cell and LCPG layer. The right-handed circularly polarized (RCP) light with the wavelength of 1550nm impinges normally upon the (incident) surface of VA LC cell.

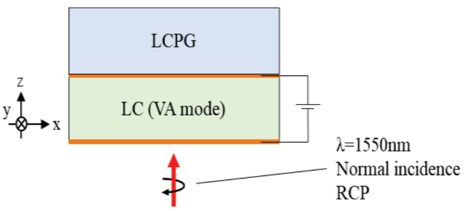


Figure 1. Simulated beam steering system.

The VA cell acts as a polarization switch driven by applying voltage. The LC directors in the off-state give no change to the incident polarization, while the cell in the on-state gives the retardation of 180 degrees.

When the the right handed circulary polarized light (RCP light) is provided as the incident light, the RCP light is applied to the LCPG if no voltage is applied to the VA cell, while the left handed circularly polarized light (LCP light) is applied to the LCPG if the on-voltage is applied. The director simulation in the VA cell was carried out with commercial software[4]. Figure 2 shows the LC orientations in the off-state and on-state.

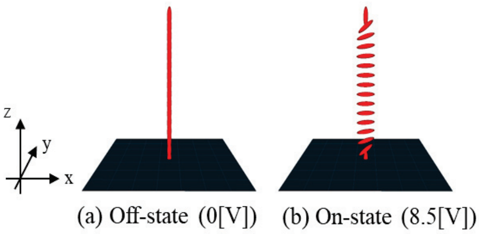


Figure 2. The LC director distribution of the VA cell.

The LCPG stacked on the VA cell is illustrated in Figure 3. The azimuth of the nematic director varies from 0 to 180 degrees uniformly during a period of 7.5μm. The LCPG switches the beam direction by handedness of incident circularly polarized light. In this model, the RCP incidence diffracts -1st order beam, while the LCP incidence diffracts +1st order one. When we define the X axis along the periodical direction and the Z axis along the thickness direction, this director orientation is given by the following equation;

$$
\begin{aligned}
&Tilt : \theta(x) = 0[\text{deg}] \\
&Azimuth : \varphi(x) = 180[\text{deg}] \times \frac{x}{\Lambda}, \quad 0 \le x \le \Lambda
\end{aligned}
\tag{1}
$$

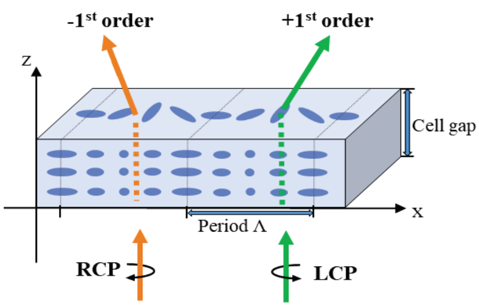


Figure 3. LC polarization grating.

The optical response in LCPG is performed by the RCWA technique. The technique is based on the Fourier series expansion of the dielectric periodicity $\varepsilon_{ij}(x+\Lambda)=\varepsilon_{ij}(x)$ in the form

$$\varepsilon_{ij}(x)=\sum_{m=-\infty}^{\infty}\varepsilon_{ij}^{m}e^{im\frac{2\pi}{\Lambda}x}, \quad i,j=x,y,z \quad (2)$$
$$\varepsilon_{ij}^{m}=\int_{0}^{\Lambda}\varepsilon_{ij}(x)e^{-im\frac{2\pi}{\Lambda}x}dx$$

The latter equation in (2) gives the Fourier coefficient. By considering Floquet's theory, the electromagnetic field in the LCPG layer can also satisfy the periodicity. Hence the fields can be represented by the Fourier series

$$E_i(x,z)=\sum_{m=-\infty}^{\infty}E_i^m(z)e^{ik_0\left(\sin\theta+m\frac{2\pi}{\Lambda}\right)x}, \quad i=x,y,z$$
$$H_i(x,z)=\sum_{m=-\infty}^{\infty}H_i^m(z)e^{ik_0\left(\sin\theta+m\frac{2\pi}{\Lambda}\right)x}, \quad i=x,y,z \quad (3)$$

Then, we substitute the equation (2) and (3) into the maxwell equations. We truncate the Fourier series by an integer M and solve the Maxwell equations in the Fourier space. Finally, we get the diffracted field.

## 3 Results and discussion

Firstly, we simulated the diffraction efficiency defined as transmittance at the steady state of each Off/On-state. Figure 4 shows the transmittance of diffraction angles. At off-state, the transmittance of the -1$^{st}$ order reached maximum 90% at an angle of -11.9 degrees to the surface normal. At on-state, that of the +1$^{st}$ order was the highest with the same value. We achieved the steering angle width as 23.8 degrees keeping almost 90% just by switching applied voltages.

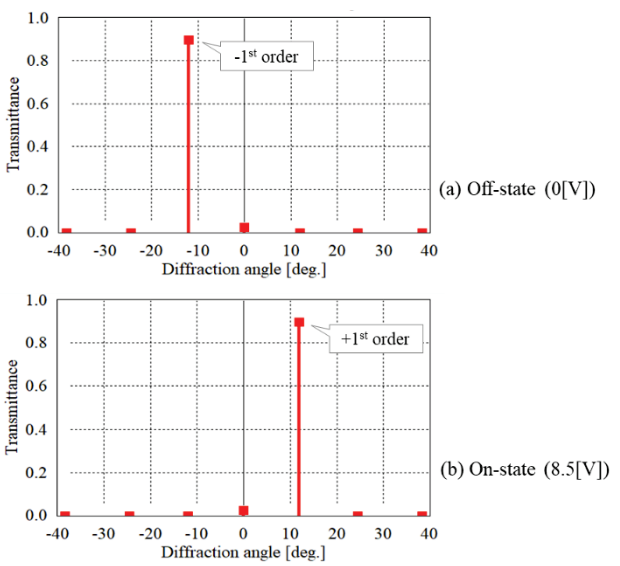


Figure 4. Switching efficiency in the steady state.

The degradation of the transmittance derives from the reflection loss on both substrates. Thus, we can easily compensate it by additional stacking of dielectric multilayers into the model.

Secondly, we simulated dynamic response for switching beams between -1$^{st}$ and +1$^{st}$ order as shown in Figure 5. We started applying a voltage at 10 ms and calculated response time defined as the period between 10% and 90% of the dynamic range. Both response curve of -1$^{st}$ and 1$^{st}$ order was completely symmetry and the response times were 15 ms. The transmittance of the 0$^{th}$ order and the total value between -1$^{st}$ and +1$^{st}$ order were constant. Accordingly, the diffracted light directly switched from -1$^{st}$ to +1$^{st}$ order without the other orders' beam emitting. These characteristics are apparently simple but difficult to estimate exactly without simulation.

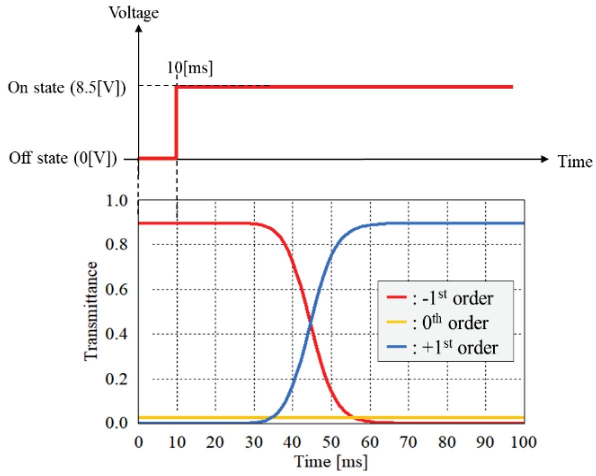


Figure 5. Time response of the beam steering system. The upper graph shows the step-waveform applying voltage. The lower shows the switching efficiency.

## 4 Conclusions

In this study, we totally simulated the switching efficiency and the switching response of LCPG stacked on a VA cell. Such numerical approach provides us various kinds of viewpoints or ideas to create novel LC-grating devices without prototyping. Numerical modeling is essential to develop LC-based beam steering devices efficiently.

## References


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