Diffraction Properties of Binary-type Liquid Crystal Gratings in the Terahertz Region: Numerical Investigation

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***Abstract*—We performed a numerical evaluation of the diffraction efficiency of a liquid crystal (LC) grating with binary phase and amplitude distribution profiles based on the Jones calculus of a terahertz wave transmitted through the LC layer. The optimum LC layer thickness for maximum diffraction efficiency was revealed to be much shorter than the LC layer thickness for a π phase difference in the binary phase distribution profile.**

I. INTRODUCTION

LIQUID crystal (LC) is a well-known field-controllable optical material that can be applied to many optoelectronic devices, such as displays, spatial light modulators, lenses, and diffractive optical elements. LC materials feature high optical transparency and large birefringence, which can easily be controlled by a low-voltage application in the visible region. It has been demonstrated that this large birefringence of LC materials can be maintained even in the terahertz (THz) region, and LC materials have attracted attention owing to their applicability in efficient THz wave-controlling devices with a low-operation voltage [1].

As mentioned above, most commercially available nematic material is highly transparent in the visible region. However, the absorption of the incident electromagnetic wave is usually not small in the non-visible region. Furthermore, LC materials exhibit large anisotropy in the absorption, depending on the orientation direction of the LC molecules. Therefore, we have to take into account this large absorption anisotropy in the case of device design and assessment of device performance.

In this work, we discuss the diffraction properties of an LC grating with a simple binary distribution profile of LC molecular orientation. Together with the birefringence ($\Delta n = n_e - n_o$), two absorption coefficients (α_e and α_o) are incorporated with the calculation of the diffraction efficiency of the LC grating. (α_e and α_o are absorption coefficients in the directions parallel and perpendicular to the orientation direction, respectively.)

II. CALCULATION RESULTS OF DIFFRACTION EFFICIENCY

Figure 1 shows a schematic view of the LC grating we investigated. The orientation direction alternates in the x direction with a period of Λ. The LC molecular orientation is uniform in both the y- and z-directions. The diffraction properties can be evaluated by carrying out a Fourier transform of the Jones vector of the output THz wave, $\mathbf{E}_o$, using the following equation:

$$\mathbf{E}_o' = \frac{1}{\Lambda}\int_0^{\Lambda} \mathbf{E}_o \exp\left(-i\frac{2\pi m x}{\Lambda}\right)dx\,. \qquad (1)$$

As shown in Fig. 2, we evaluated the LC layer thickness dependence of diffraction efficiencies for the zeroth ($m = 0$) and first ($m = 1$) orders, where $\lambda = 117$ μm, $\Delta n = 0.17$, $\alpha_e = 55\ \mathrm{cm}^{-1}$, and $\alpha_o = 80\ \mathrm{cm}^{-1}$. When the thickness d increases from zero, the first-order diffraction efficiency η_1 also increases (the maximum value is 2.53×10^{-3} at $d = 149$ μm). Provided that the LC material we used is fully transparent ($\alpha_e = 0$ and $\alpha_o = 0$), the maximum diffraction efficiency should be obtained when $\Delta nd/\lambda = \pi$; that is, $d = 2162$ μm. We can conclude that the optimum LC layer thickness for the maximum diffraction efficiency (149 μm) is much smaller than 2162 μm due to the anisotropy in the THz wave absorption.

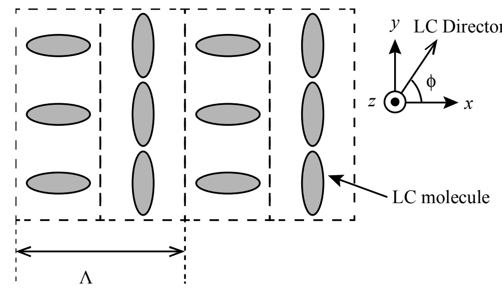

Fig. 1. Top view of an LC grating with a binary distribution of LC molecular orientation, where the LC molecular orientation is uniform in the z-direction: Λ is the grating period; ϕ is the angle between the LC director (direction of the LC molecular axis) and the x axis.

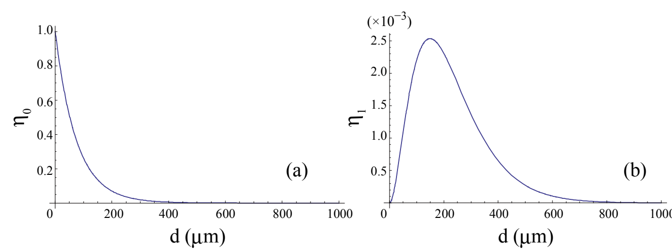

Fig. 2. Calculated LC layer thickness dependence of (a) zeroth- and (b) first-order diffraction efficiencies, where the polarization direction of the incident THz wave is parallel to the x-axis.

III. SUMMARY

The diffraction efficiency of an LC grating with simple binary phase and amplitude profiles was evaluated numerically. The results of our evaluation indicate that the LC layer thickness for the maximum first-order diffraction efficiency is much smaller than that for a π phase difference in the binary phase distribution profile, indicating that the absorption anisotropy has a major influence on the diffraction properties, as is true of birefringence.

REFERENCES

[1]. R. Ito, M. Honma, T. Nozokido, T. Nose, "Terahertz Liquid Crystal Grating Fabricated by Using Microrubbing Process," *The 20th International Display Workshops*, pp. 223-224, Sapporo, Japan, Dec. 4–6, 2013.