Light Propagation Analysis in Holographic Data Storage Using a Refractive Parameter

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1 Introduction

In order to analize the noise generated from a holographic data storage, light propagation analysis in the volume hologram is required. The volume hologram consists of refractive index distribution. Conventional light propagation analysis methods in a medium with refractive index distribution are based on numerical analysis such as RCWA and FDTD. However, the calculation volume is limited to a small volume in the numerical methods. In this study, an analytical function based method is proposed.

2 Proposed method

When the change in electric susceptibility χ is linear to light intensity, χ is expressed by

$$\chi(\boldsymbol{r}) \propto |W_{\mathrm{S}}(\boldsymbol{r}) + W_{\mathrm{R}}(\boldsymbol{r})|^2 \tag{1}$$

, where W_{S}, W_{R} are signal and reference waves. Here, a refractive parameter α is introduced and χ is rewritten as

$$\chi(\boldsymbol{r}, \alpha) = \alpha H(\boldsymbol{r}), \tag{2}$$

where H is a volume hologram function. The wave equation satisfied in the volume hologram is expressed by

$$\nabla^2 W(\boldsymbol{r}, \alpha) + [1 + \chi(\boldsymbol{r}, \alpha)] W(\boldsymbol{r}, \alpha) = 0, \tag{3}$$

where W is a solution and can be expanded by

$$W(\boldsymbol{r}, \alpha) = \sum_{m=0}^{\infty} \frac{1}{m!} \frac{\partial^m W(\boldsymbol{r}, 0)}{\partial \alpha^m} \alpha^m. \tag{4}$$

In the case of $\alpha = 0$, eq.(3) is rewritten as

$$\nabla^2 W(\boldsymbol{r}, 0) + (1 + \chi_0) W(\boldsymbol{r}, \alpha) = 0. \tag{5}$$

This equation is a Helmholz equation so that plane wave solution is obtained. The plane wave solution is used as an incident beam to the volume hologram. When eq.(3) is differentiated by α and in the case of $\alpha = 0$,

$$\nabla^2 \frac{\partial W(\boldsymbol{r}, 0)}{\partial \alpha} + (1 + \chi_0) \frac{\partial W(\boldsymbol{r}, 0)}{\partial \alpha} = -H(\boldsymbol{r}) W(\boldsymbol{r}, 0), \tag{6}$$

is obtained. This equation is inhomogeneous HelmHolz equation so that the solution can be written by Green's function method as follows:

$$\frac{\partial W(\boldsymbol{r}, 0)}{\partial \alpha} = \int_V \frac{\exp\left(\mathrm{i}k\sqrt{1+\chi_0}|\boldsymbol{r} - \boldsymbol{r}'|\right)}{4\pi|\boldsymbol{r} - \boldsymbol{r}'|} H(\boldsymbol{r}') W(\boldsymbol{r}', 0) \mathrm{d}^3\boldsymbol{r}'. \tag{7}$$

Similarly, mth derivatives are expressed by

$$\nabla^2 \frac{\partial^m W(\boldsymbol{r}, 0)}{\partial \alpha^m} + (1 + \chi_0) \frac{\partial^m W(\boldsymbol{r}, 0)}{\partial \alpha^m} = -H(\boldsymbol{r}) \frac{\partial^{m-1} W(\boldsymbol{r}, 0)}{\partial^{m-1}}. \tag{8}$$

Thus, mth derivative can be sequencially obtained by$m-1$th derivative and the solution expressed by eq.(4) is obtained.

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