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BOUNDARY-ELEMENT METHOD ANALYSIS OF THE INTENSITY DISTRIBUTION OF A LIGHT BEAM IN A PHOTORESIST LAYER IN MASTERING PROCESS OF OPTICAL DISCS

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INTRODUCTION Various types of optical discs have been proposed and put to practical use as a medium with which to realize high-density and high-speed recording of information. In order to realize a high-density version of the conventional optical disc, we have analyzed the light-beam scattering from various pit models on the conducting plane, at the interface between two dielectric media, or at the interface of the three-layered dielectric media by using the boundary element method(1)-(3). The results obtained from these analyses show that it is possible to achieve higher information density by optimizing the sizes of the groove and the beam spot. On the other hand, in order to realize such models, it is required to cut the desirable surface relief pattern on the so-called master disc in mastering process. The master is a flat glass substrate coated with a thin phtosensitive material(resist). The surface relief pattern is recorded by exposing the photoresist using a focused laser beam whose intensity is modulated in accordance with the information. In the exposed areas light is absorbed which has the effect of locally changing the solubility of the layer(4). The local solubility depends on the absorbed light power.

The purpose of the present paper is to analyze the intensity distribution of the light in the photoresist layer illuminated by the focused laser beam. The boundary-element method based on the integral equation is applied to the present problem. Several numerically simulated results of the intensity distribution are presented for different values of the layer width and medium constants.

FORMULATION The model for analysis in this paper is shown in Fig. 1. The regions Ω_1 , Ω_2 , and Ω_3 are three different dielectric media whose permittivity and permeability are (ε_1, μ_1), (ε_2, μ_2) and (ε_3, μ_3). The regions Ω_1 , Ω_2 , and Ω_3 are assumed to be a glass substrate, a photoresist layer and free space, respectively. The focused laser light-beam wave , which is initially described in the coordinate system (x_1,y_1), is incident from the region Ω_3 . The origin of the coordinate system (x_1, y_1) is located at $x=x_0$ and $y=y_0$ and the beam axis coincides with the y_1 axis. Let the angle ϕ between the y_1 and y axes be an incident angle of the beam. We assume that a scalar function u satisfies the two-dimensional Helmholtz equation in each region and represents the electric or magnetic field component in the z direction for E- or H-polarized wave. Applying Green's theorem to the scalar function, we obtain the integral expression for each u at an arbitrary point of observation r in each region as follow:

[1] $\mathbf{r} \in \Omega_1$

$$u_1(\mathbf{r}) = \int_{\Gamma_{12}} \{u_1(\mathbf{r}')\frac{\partial G_{k1}(\mathbf{r},\mathbf{r}')}{\partial n'_{12}} - G_{k1}(\mathbf{r},\mathbf{r}')\frac{\partial u_1(\mathbf{r}')}{\partial n'_{12}}\}\, d\Gamma \qquad (1)$$

[2] $\mathbf{r} \in \Omega_2$

$$u_2(\mathbf{r}) = \int_{\Gamma_{12}} \{u_2(\mathbf{r}') \frac{\partial G_{k2}(\mathbf{r},\mathbf{r}')}{\partial n'_{12}} - G_{k2}(\mathbf{r},\mathbf{r}')\} \frac{\partial u_2(\mathbf{r}')}{\partial n'_{12}}\} d\Gamma + \int_{\Gamma_{23}} \{u_2(\mathbf{r}') \frac{\partial G_{k2}(\mathbf{r},\mathbf{r}')}{\partial n'_{23}} - G_{k2}(\mathbf{r},\mathbf{r}') \frac{\partial u_2(\mathbf{r}')}{\partial n'_{23}}\} d\Gamma \quad (2)$$

[3] $\mathbf{r} \in \Omega_3$

$$u_3(\mathbf{r}) = -\int_{\Gamma_{23}} \{u_3(\mathbf{r}') \frac{\partial G_{k3}(\mathbf{r},\mathbf{r}')}{\partial n'_{23}} - G_{k3}(\mathbf{r},\mathbf{r}') \frac{\partial u_3(\mathbf{r}')}{\partial n'_{23}}\} d\Gamma + u_3^{inc}(\mathbf{r}) \quad (3)$$

where r' is the position vector subject to the boundary integral and n' is the normal vector component at r'. $u_3^{inc}(r)$ is the incident beam. $G_{ki}(r,r')$ represents a two-dimensional Green's function in each region as

$$G_{ki}(\mathbf{r},\mathbf{r}') = -(j/4) H_0^{(2)}(k_i \mid \mathbf{r}' - \mathbf{r} \mid), \quad i=1,2,3 \quad (4)$$

where k_i is the wave number in Ω_i and $H_0^{(2)}$ is the Hankel function of the second kind of order zero.

After taking the limit such that the observation point r approaches each boundary and considering both the singularity of the Green's function and the boundary condition, the following integral equations are obtained:

$$\int_{\Gamma_{12}} \{u_{12}(\mathbf{r}') \frac{\partial G_{k1}(\mathbf{r},\mathbf{r}')}{\partial n'_{12}} - \gamma_{12} G_{k1}(\mathbf{r},\mathbf{r}') q_{12}(\mathbf{r}')\} d\Gamma + C_{12} u_{12}(\mathbf{r}) = 0 \quad (5)$$

$$\int_{\Gamma_{12}} \{u_{12}(\mathbf{r}') \frac{\partial G_{k2}(\mathbf{r},\mathbf{r}')}{\partial n'_{12}} - G_{k2}(\mathbf{r},\mathbf{r}') q_{12}(\mathbf{r}')\} d\Gamma + \int_{\Gamma_{23}} \{u_{23}(\mathbf{r}') \frac{\partial G_{k2}(\mathbf{r},\mathbf{r}')}{\partial n'_{23}} - \gamma_{23} G_{k2}(\mathbf{r},\mathbf{r}') q_{23}(\mathbf{r}')\} d\Gamma - C_{12}' u_{12}(\mathbf{r}) = 0 \quad (6)$$

$$\int_{\Gamma_{23}} \{u_{23}(\mathbf{r}') \frac{\partial G_{k3}(\mathbf{r},\mathbf{r}')}{\partial n'_{23}} - G_{k3}(\mathbf{r},\mathbf{r}') q_{23}(\mathbf{r}')\} d\Gamma + C_{23} u_{23}(\mathbf{r}) = u_3^{inc}(\mathbf{r}) \quad (7)$$

$$\int_{\Gamma_{12}} \{u_{12}(\mathbf{r}') \frac{\partial G_{k2}(\mathbf{r},\mathbf{r}')}{\partial n'_{12}} - G_{k2}(\mathbf{r},\mathbf{r}') q_{12}(\mathbf{r}')\} d\Gamma + \int_{\Gamma_{23}} \{u_{23}(\mathbf{r}') \frac{\partial G_{k2}(\mathbf{r},\mathbf{r}')}{\partial n'_{23}} - \gamma_{23} G_{k2}(\mathbf{r},\mathbf{r}') q_{23}(\mathbf{r}')\} d\Gamma - C_{23}' u_{23}(\mathbf{r}) = 0 \quad (8)$$

where u_{12} and u_{23} stand for u on the boundaries Γ_{12} and Γ_{23}, and q_{12}

and q_{23} the normal derivatives of them. The constants C_{12}, C_{12}', C_{23}, and C_{23}' are given by

$$C_{12}=1-C_{12}', \quad C_{12}'=\theta_{12}/2\pi, \; C_{23}=1-C_{23}', \; C_{23}'=\theta_{23}/2\pi \tag{9}$$

where θ_{12} or θ_{23} is the angle of corner where the point of observation r is located at the corner of each boundary. $⨍$ means the Cauchy's principal value of integration. The constants γ_{12} and γ_{23} are given by

$$\gamma_{12}=\mu_1/\mu_2, \quad \gamma_{23}=\mu_2/\mu_3 \quad \text{for E-polarization}$$

$$\gamma_{12}=\varepsilon_1/\varepsilon_2, \quad \gamma_{23}=\varepsilon_2/\varepsilon_3 \quad \text{for H-polarization} \tag{10}$$

In order to carry out the integrals in (5) through (8) and obtain the solutions of the simultaneous integral equations, discreization of the integrals is required. Each element of the resultant matrix equation can be obtained from numerical integrations of the Hankel function as Green's function and the interpolation functions of u and q. In this analysis, we use linear interpolation functions. The solutions of the matrix equations represent the surface current density on each boundary. By using those solutions in (2), we obtain the field component in the photoresist layer.

NUMERICAL RESULTS Numerical examples of the intensity distribution of the light beam in the photoresist layer are shown in Fig. 2 for the case where the E-polarized focused beam is normally incident on the layer. The relative permittivities of the photoresist layer and the glass substrate are chosen to be 2.56 and 2.31, respectively, and the layer width to be a quarter of the wavelength in free space. The numerical aperture of the object lens is chosen to be 0.8 in Fig 2(a) and 0.6 in Fig.2(b). Therefore, the corresponding values of the beam diameter at its focal plane become 1.2 and 1.6 times of the wavelength, respectively. The area of a black circle is proportional to the intensity of the transmitted light. The reflection at the interface between the photoresist layer and the glass substrate is considerable small, and so the interference between the forward and backward waves in the layer is very weak. However, it can be observed that a standing-wave behavior occurs slightly in the y direction. On the other hand, when the light beam is incident from the glass region, a strong standing-wave can occur in the layer.

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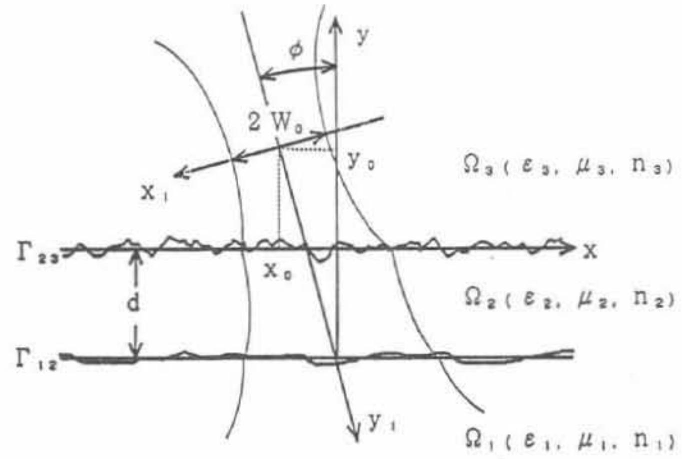
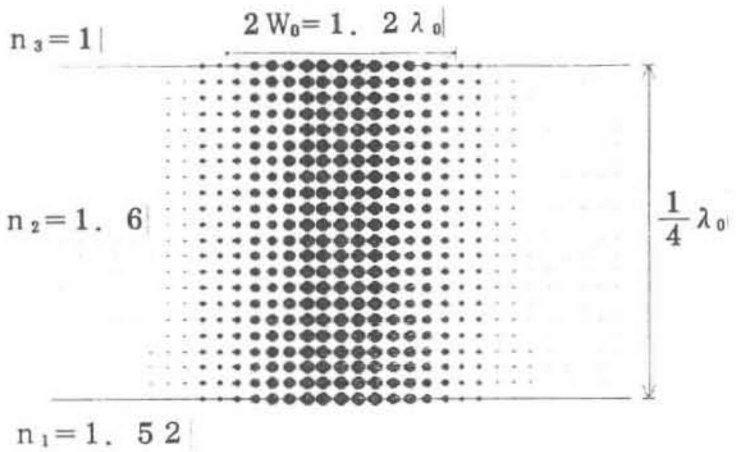
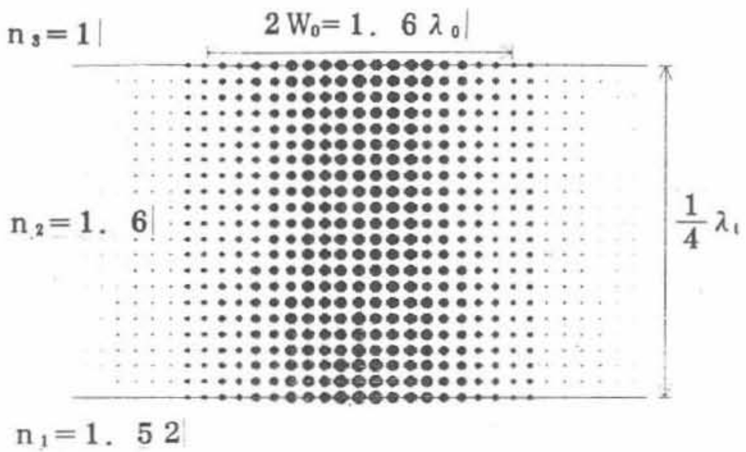


Fig.1. Geometry of the problem.



(a) NA=0.8, y_0=0



(b) NA=0.6, y_0=0

Fig.2. Intensity distribution of light beam in photoresist layer.