Optical Method for Investigation of the Parameters of the Thin Film

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Abstract— We present results of computer simulation and experimental observation of the Gauss beam reflection from a thin film (an one-dimension photonic crystal). The beam splitting and the beam center of gravity shift were demonstrated after the beam reflection. The shifts were different for s and p-polarization and depended on the angle of incidence, the film thickness and the refractive indices of the film and the substrate. The computer generated intensity distributions and experimentally observed ones after the beam reflection were used to determine the film thinkness.

1. INTRODUCTION

Snell's laws were formulated for rays. They are not true for laser beams. The special behavior of light beams under the total internal reflection was considered in Ref. [1]. The longitudinal shift of the linearly polarized beam under the total internal reflection was predicted in 1929 [6]. The magnitude of the shift (Goos-Hanchen shift) was of the order of the wavelength and depended on the radiation polarization. This shift was observed experimentally under the propagation of the linearly polarized radiation of different azimuths through a planar waveguide [2–5].

The transverse shift of the circularly polarized light beam under the total internal reflection was predicted in 1955 [6]. The transverse shift (Fedorov-Imbert shift) was comparable-sized the wavelength and the direction of the shift depended on the sign of the circular polarization [6, 7]. The beam transverse shift was observed experimentally under the circularly polarized beam propagation through a multifaceted prism [8–10].

The Goos-Hanchen and Imbert-Fedorov shifts are spatial shifts. The longitudinal [11] and transverse [12] spatial shifts were observed under the polarized light reflection from a metal surface. The theoretical description of the transverse shift of the polarized beams can be find in Refs. [14, 15]. Spatial shifts under reflection and refraction of the polarized beam at a non-metallic surfaces were described [13].

The deviation of the angle of reflection from the angle of incidence was described in [16]. This shift was named the angular Goos-Hanchen shift.

The Fedorov-Imbert angular displacement was predicted for the first time in Ref. [18]. The magnitude of the angular shift was proportional to the second degree of the wavelength. The Fedorov-Imbert angular displacement was observed experimentally when light was reflected from a metal surface [12].

The values of the described shifts are small. The shifts can be increased by reflection from a layed surface. It was shown theoretically that the reflection of the Gaussian beam from a thin film resulted in the beam deformation and longitudinal shift. It was found that the shift value and the deformation depended on the film thickness and refractive indecies of the film and substrate.

Here we describe the method of determination of the thin film parameters using the Gaussian beam deformation under reflection from a thin film.

2. THEORETICAL RESULTS

We calculated the Gauss beam reflection from a film as follows. The angle of the beam incidence was α_0. The wave equation was solved by the spectral method. The Gauss beam was decomposed into plane waves in the certain range of angles. As a result we got the set of plane waves. The reflection coefficient r_s, r_p for each s- and p-polarized plane wave were calculated using the Fresnel formulas. We used the folowing parameters. The refractive index of the film n_f was equal to 1.596 (photoresist SU $-$ 8). The refractive index of the substrate was equal to $n_\mathrm{s} = 3.62$ (silicon). The wavelength $\lambda = 0.63\,\mu\mathrm{m}$. The film thikness was changed from 15 μm to 35 μm. The obtained reflection coefficient $R_s = |r_s|^2$ and $R_p = |r_p|^2$ are shown in Fig. 1.

Figure 1 also shows the angular spectra of the Gauss beam under consideration. The angular width of the beam equals 7°. It can be seen that the Gausian beam covers the maximum and minimum of the reflection coefficients, that can predict the Gauss beam deformation.

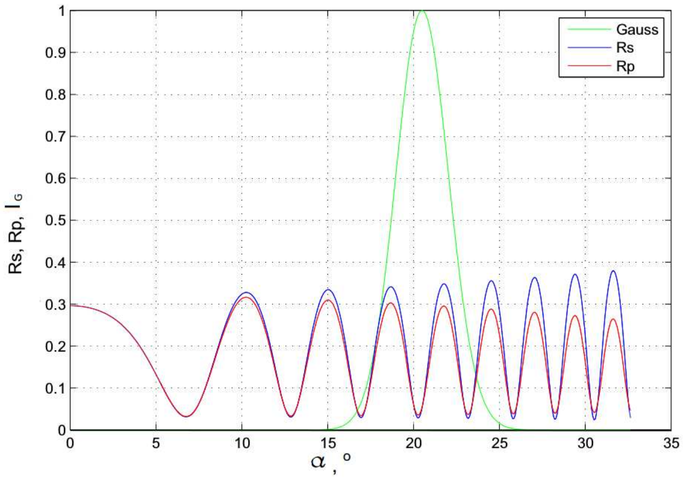

Figure 1: Reflection coefficients R_s, R_p and the angular spectra of the Gauss beam as a function of the incedence angle α.

The calculated intensity images were used to determine the center of the gravite of the reflected beam. The transverse shift wasn't observed. Figure 2 shows the dependence of the longitudinal spatial shift of the reflected Gauss beam on the angle of incidence for the different light polarizations. We can see from Figure 2 that the longitudinal shift can be positive or negative. It should be stressed that multipath light propagation through the film leads to increasing of the longitudinal spatial shift.

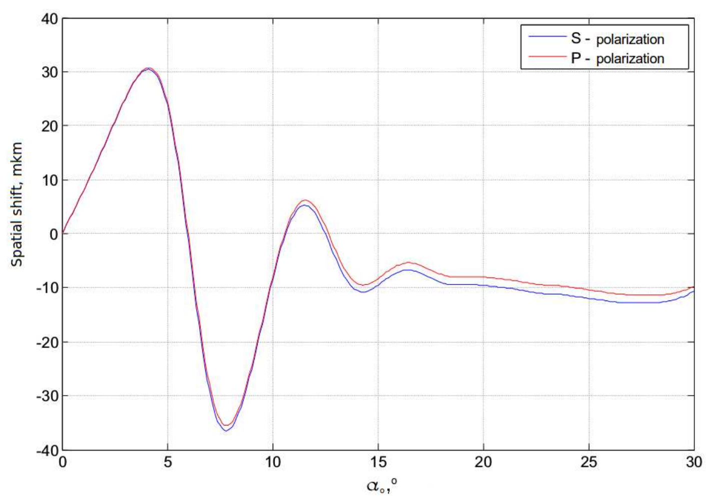

Figure 2: The dependence of the polarized beam longitudinal shift on the angle of incidence α.

To determine the angular shifts the propagation of the reflected beam was simulated and the intensity distribution in the far field was calculated. The angular shift of the beam center of gravity was determined by the deviation from the classical law of reflection. The angular longitudinal shift dependence on the angle of incidence for different polarizations. It can be seen from Ref. [2] that the angular shift depends on the angle of incidence quasi-periodicaly and doesn't depend on the polarization of the incident radiation. The shifts deviations are both positive and negative, the maximum value is about $-1.7°$.

3. EXPERIMENTAL RESULTS

The s-polarized reflected beam was investigated experimentally under the beam reflectoin from a photoresist film deposited on a silicon substrate. The angle of incidence was in the range from 5° to 24°. The beam intensity distribution was observed at a screen installed at the distance of 87 mm from the reflecting film. The image was projected at CCD camera by a lens with the focal length

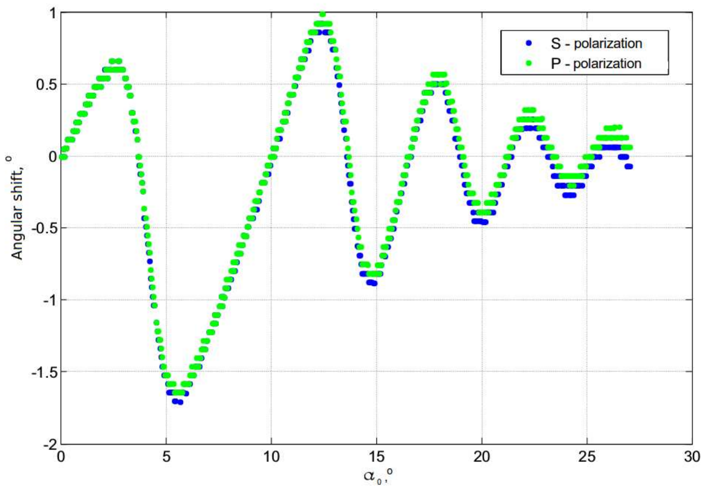

Figure 3: The dependence of the angular shift of reflection polarized beam on the angle of incidence.

$f = 25.4\,\text{mm}$. The divergence angle of the beam was approximately equal to 6°.

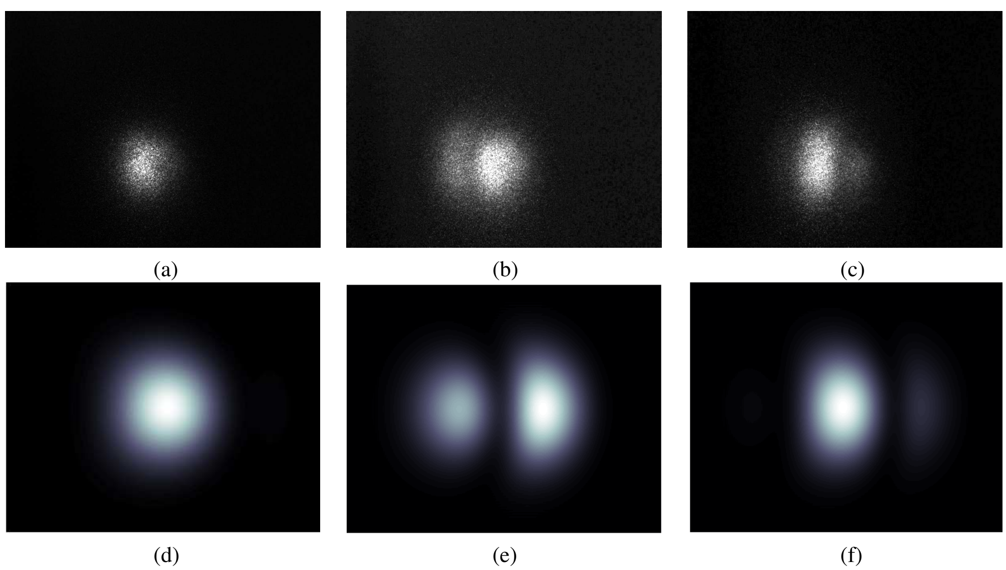

Figure 4: Experimentally observed (a), (b), (c) and calculated (d), (e), (f) intensity distributions of the reflected beam at the angles of incedence $\alpha_0 = 10°$ (a), (d), $\alpha_0 = 20°$, (b), (e), $\alpha = 24.5°$ (c), (f).

Figures 4(a), 4(b), 4(c) show the registered beam intensity distribution for the different angles of incidence α_o. Figures 4(d), 4(e), 4(f) show the calculated beam intensity distribution after reflection from the film with the thickness 28 μm at the same angles of incidence. The thikness of the film under investigation was measured independenty and the film thikness turned out to be 28 μm. The agreement between the experimental results and the results of the computer simulation allows us to use those intensity distributions for the film thikness determination.

4. CONCLUSION

The beam splitting and the beam center of gravity shift after the beam reflection were calculated. The shifts were different for s and p-polarization and depended on the angle of incidence, the film thickness and the refractive indices of the film and the substrate.

The Gauss beam spliting was observed experimentally at the different angles of incidence. It was shown that the beam deformation under the reflection can be used for the films parameters determination.

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