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EVANESCENT – WAVE RECORDING IN VERY THIN LAYERS

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The theoretical background of optical holographic recording in very thin films is given. The interference fringes are stored by surface – propagating evanescent waves. Such waves are created by the total internal light reflection (TIR). The experimental verification of the theory is made. The holographic grating with 454nm period has been recorded in 29, 39 and 74 nm thick As₂S₃ films. The diffraction efficiency dependence on the time is investigated. The polarization behavior of TIR surface holograms is similar to that of the thick Bragg gratings. The possible applications of this holographic recording are also discussed.

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1. Introduction

Arsenic trisulfide (As₂S₃) films possess interesting optical characteristics that enable them to be used as holographic storage media. For the first time Keneman [1] has reported such grating recording in evaporated As₂S₃ films. The diffraction efficiency (DE) of 80% is obtained in 10 μm and several percent – in 2μm thick film.

Later on, Japanese scientists using waveguide technique [2] have successfully made the recording in 250 nm As₂S₃ film. In thinner films the holographic recording is possible using the total internal reflection (TIR) method, first reported by Stetson [3] The recording is realized by the interference between TIR reference wave and plane object wave. Earlier, we have demonstrated TIR grating recording in 70 nm As₂S₃ film [4].

In this paper we present for the first time the TIR holographic recording in 29, 39, and 74 nm evaporated thin As₂S₃ films.

We first describe the principle of the surface TIR recording in thin layers. Then, we show experimental results involving the exposure dependence on DE and polarization characteristics of the recorded gratings. Some possible applications of this holographic recording are finally discussed.

2. Theoretical background

Let us consider the interference between plane wave,

$$E_p = E_{0p} \cdot \exp\left(i \frac{2\pi}{\lambda_0} n_1 z\right)$$

and TIR referent wave

$$E_{TIR} = E_{0TIR} \cdot \exp\left(-\frac{z}{z_0}\right) \cdot \exp\left(i \frac{2\pi}{\lambda_0} n_1 x \cdot \sin \varphi\right)$$

as it is shown in Fig.1.

The angle of incidence φ condition for TIR at the interface between optically denser first medium with refractive index n_1 and second with n_2 is $\varphi > \arcsin\left(\frac{n_2}{n_1}\right)$ and the characteristic length z_0 , where electric field amplitude E falls to e^{-1} of its value is given by

$$z_0 = \frac{\lambda_0}{2\pi n_1 (\sin^2 \varphi - n_{21}^2)^{1/2}} \tag{1}$$

λ_0 is the vacuum wavelength, $n_{21} = \frac{n_2}{n_1}$

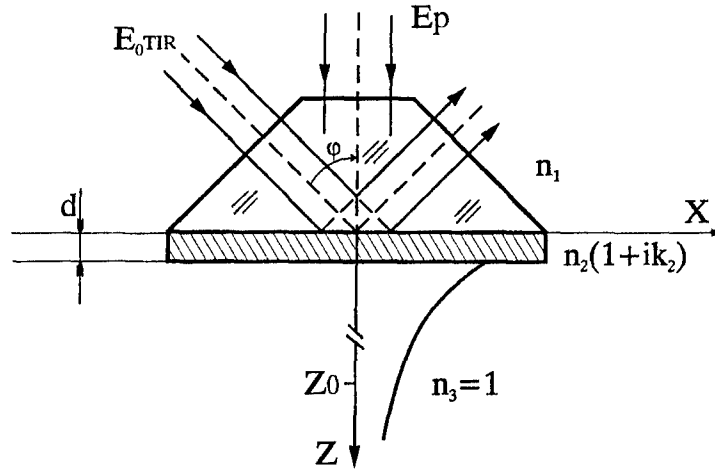


Fig. 1. Optical configuration for TIR surface holographic recording with an evanescent reference wave.

Near the reflecting surface $z = 0$ the interference pattern is described by

$$E_{12} = E_{0p}^2 + E_{0TIR}^2 \cdot \exp\left(-\frac{2z}{z_0}\right) + 2E_{0p}E_{0TIR} \exp\left(\frac{-z}{z_0}\right) \cos \Phi \tag{2}$$

with the phase $\Phi = 2\pi\left(\frac{n_1 x \sin \varphi}{\lambda_0} - \frac{zn_2}{\lambda_0}\right)$

If the second, optical recording medium is much thinner than z_0 , i. e. $d \ll z_0$ the interaction between the interference pattern and the recording medium (with complex refractive index $n_2^* = n_2(1 + i\kappa_2)$) can be described, following Harrick [5], with a "effective thickness", given by

$$d_e = \frac{4dn_2 n_1 \cos \varphi}{(n_1^2 - 1)} \tag{3}$$

It is very interesting that, in the case when $\frac{2\pi dn_1}{\lambda_0} \ll 1$ and $\kappa_2 \ll 1$ the TIR does not depend on the refractive index of the second, recording medium, that can be higher than the refractive index of the first medium. In this case, the TIR condition is $\varphi > \arcsin\left(\frac{1}{n_1}\right)$. For $n_1 = 1.5$, $n_2 = 2.5$, and $\varphi = 45^\circ$ we have $\left(\frac{d_e}{d}\right) = 8.5$ and the plane wave – recording medium interaction can be neglected. In this case, the interference term can be written as

$$E_{12} = E_{0p}^2 + E_{0TIR}^2 (1 - \alpha d_e) + 2E_{0p}E_{0TIR} (1 - \alpha d_e) \cos \Phi \tag{4}$$

here the phase Φ and the absorption coefficient α are, respectively $\Phi = \frac{n_1 x \sin \varphi}{\lambda_0}$ and $\alpha = \frac{4\pi n_2 \kappa_2}{\lambda_0}$. The grating period Λ over X – axis is

$$\Lambda = \frac{\lambda_0}{n_1 \sin \varphi} \tag{5}$$

Supposing $E_{0p} = E_{0TIR} = E_0$, the relation (4) can be written as $E_{12}^2 = E_{12(\alpha=0)}^2 (1 - \alpha d_e / 2)$, where

$$E_{12(\alpha=0)}^2 = 4E_0^2 \cos^2 \pi m_1 x \sin \varphi / \lambda_0 \quad (6)$$

3. Results and discussion

3.1. Sample preparation

The experiments are performed with as – deposited thin films of an As_2S_3 having thickness between 5 and 75 nm. The samples are prepared in the Central Laboratory of Photoprocesses, Bulgarian Academy of Sciences. The films have been obtained by a vacuum deposition of high purity As_2S_3 at a residual pressure in the order 6.10^{-4} Pa. A deposition rate of 0.1 nm/s has been achieved at an evaporation temperature of 240°C . The film thickness is measured by Talystep profilograph, Code 112/1037 M-S, produced by Rank Taylor Hobson Ltd.

3.2. Optical recording and measurements

The optical arrangement is shown in Fig. 2. Ar^+ - ion laser has been used as a light source. The beam intensities are adjusted for an optimal 1 : 1 ratio (10 mW/cm^2 each) with a beam splitter (BS) and gray filter (GF).

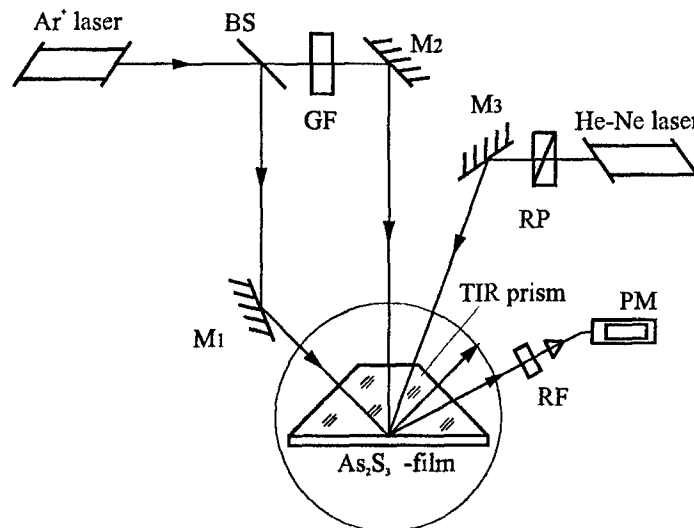


Fig. 2. Optical arrangement for evanescent holographic recording.

Our TIR prism is made of light crown K – 8 with refractive index $n_1 = 1.522$ for $\lambda_0 = 488\text{nm}$. The angle of incidence φ is 45° , to which grating period $\Lambda = 454\text{nm}$, or spatial frequency 2200line/mm is corresponded. The polarization of the monitoring He – Ne laser is changed from s to p – polarization with rotator (RP). The diffraction efficiency is measured with an Ealing 911 powermeter through a red filter (RF).

The exposure time is changed in 0.5 – 20s region, that correspond to $10 - 400\text{mJ/cm}^2$ exposure.

In Fig. 3a the diffraction efficiency dependence on the exposure is shown for three different thickness of the recording medium – 29, 39 and 74nm. The best result is obtained for 39 nm thin film, where 0.15% efficiency has been measured. The recorded grating in $\text{As}_2\text{S}_3 - \text{Cr}$ film is shown about three times lower efficiency, as it is clear from Fig. 3 – b. The observed shift to higher exposures is possible to be explained with the Cr layer, acting as a density filter.

The polarization properties of the recorded TIR surface gratings are similar to that of thick Bragg holograms. The theoretical treatment of Gasvik [6] gives following simple relation

$$I(\Theta)/I_s = (1 - B)\cos^2 \Theta, \text{ where } B = I_p / I_s \quad (7)$$

The polarization dependence of the diffracted intensity $I(\Theta)$ is shown in Fig. 4. The solid curve represents the theoretical calculation after (7) for thick Bragg grating. The azimuth angle of 0° corresponds to s – polarization and angle 90° – to the p – polarization. The square points are measured

values with the accuracy of 5%. Within this accuracy limit good agreement between experiment and calculation is observed.

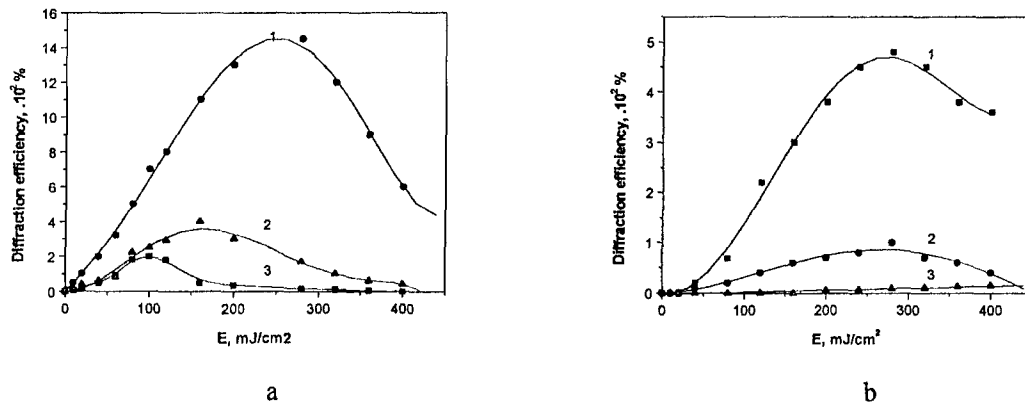


Fig. 3. The exposure dependence of the diffraction efficiency, recorded in: a) – As_2S_3 film; b) – $As_2S_3 - Cr$ film. The corresponding thickness are: 1- $d = 74nm$; 2 – $d = 39nm$; 3 – $d = 29nm$.

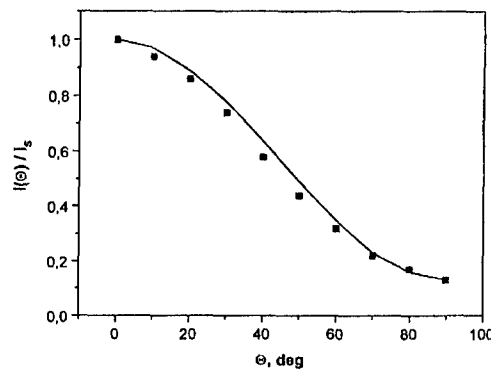


Fig. 4. The polarization azimuth dependence on the normalized diffraction intensity.

4. Conclusions

We have demonstrated for the first time a surface holographic recording in chalcogenide glass using as an optical storage medium. Very thin evaporated As_2S_3 films have been used for its large photo-induced refractive index change. The recorded TIR holograms have shown full analogy to the thick Bragg gratings.

The independence of the TIR from the refractive index of the optical storage medium is also shown which is very important for the future applications of the TIR holographic grating techniques for surface investigations. Such recording possesses also potential applications in near – field optics, submicrometer lenses, optical lithography, etc.

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