Optical Materials 32 (2010) 807–810

Contents lists available at ScienceDirect

Optical Materials

journal homepage: www.elsevier.com/locate/optmat

Surface relief formation in amorphous chalcogenide thin films during holographic recording

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ARTICLE INFO

Article history:
Received 9 September 2009
Received in revised form 10 January 2010
Accepted 14 January 2010
Available online 4 February 2010

Keywords:
Amorphous chalcogenide films
Holographic recording
Softening temperature
Surface relief
Polarization

ABSTRACT

This report present the studies of direct holographic recording of the surface relief gratings on amorphous As_2S_3 films by 532 nm laser light. By giving extra time for recording exposure (more than necessary for volume amplitude-phase optical recording, e.g. Kikineshi, 2000 [2]), changes of surface relief in the resist material can be observed. This direct surface relief formation phenomenon during holographic recording is discussed here from the side of recording light polarization. Efficiency of the relief formation may also depend on softening temperature of the film material and this influence was studied as well by using additional incoherent light for extra exposure during recording. The results show several times larger grating efficiency during recording in case of extra exposure by additional incoherent light. Also the mechanism of the direct recording of surface relief on amorphous chalcogenide films based on the photoinduced plasticity has been discussed.

1. Introduction

The key element for the production of surface relief holographic optical elements is photoresist or light sensitive material. Changes of the local chemical properties, optical parameters, microhardness, viscosity and some other characteristics [1–3] induced in the resist material by light or e-beam exposure enable the surface relief structuring by *wet* or *dry* etching. Therefore this process includes at least two steps: recording and following development by etching. Due to polarization dependent anisotropic changes in the resist material, like opto-mechanical [7], M-shaped [8] or anisotropic crack [9] deformations during exposure it is possible to obtain a structured surface relief optical elements without etching.

A number of organic and inorganic materials have been studied for direct surface relief formation during the process of exposure by light or e-beam [4–6]. It is very promising for practical applications, it makes possible to simplify the technology of surface patterning.

Also in this report the surface relief formation during holographic recording in amorphous chalcogenide semiconductor thin films is presented. A number of studies have been carried out on photoinduced structural transformation in amorphous chalcogenides during the past few years [4,10,11], but in this case particular attention is given to the polarization state of exposure light.

The intensity distribution of the two coherent, equal intensities and *p*-polarized beams interference can be approximated by sin function: $I_{local} = I_{max} \cdot \sin^2(\pi \cdot x/\Lambda)$, where Λ-period of the light interference (usually around 1 μm) and *x*-profile coordinate. This formula shows that the local intensity of the light periodically varies from zero to I_{max}, i.e. there are places where light intensity equals to zero. In case of holographic recording and direct surface relief formation during the exposure process it means that there are local unexposured places on the sample which do not participate in surface relief formation process and moreover it may disturb the relief formation efficiency. If and how can we change this situation? What happens if we during recording process extra illuminate the sample by additional incoherent light with intensity I_0, which do not participate in the surface relief formation processes? We keep the same local light gradient and lift up total local light intensity in range from I_0 to $I_0 + I_{max}$ – exposure also places where intensity of the recording beams are equal to zero. This lead to softening temperature decreasing and increasing efficiency of the direct surface relief formation during holographic recording. Main task for this report is to investigate this influence of the surface relief formation by using additional incoherent laser light for extra illumination during holographic recording.

There are other methods or techniques what cause softening temperature changes and are suitable for holography like heating of the sample during recording process etc. In our case extra exposure is more stable and easy to realize and control.

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doi:10.1016/j.optmat.2010.01.008

2. Experimental

Amorphous As_2S_3 films were obtained by thermal evaporation in vacuum of $\sim 5 \times 10^{-6}$ Torr onto the glass substrates. Thickness of the film was controlled in real time by diode laser and it was from 0.5 to 10 μm.

The surface relief formation experiments were performed using a holographic recording system (see scheme in Fig. 1a) where *Verdi*-6 532 nm wavelength laser beam was spitted into two of nearly equal intensity beams that were used for interference experiments. Diffraction efficiency (η) was controlled in real time by measuring the first order intensity of the reflected and transmitted recording beams. During holographic recording the changes in volume were controlled by measuring the transmission diffraction efficiency (DE) η_T (like those in absorption and refractive index). The changes in surface relief modulation were controlled by measuring the reflection DE η_R. The volume gratings also affect the reflection DE, however contribution is insignificant (see [2]) and will not be discussed here.

For future data analysis we need to define some parameters like recording efficiency that is defined as the slope of the first order polynomial equation $\eta = c_0 \cdot t$, i.e. $c_0 = \Delta\eta/\Delta t$ (here t is the time of exposure). The enhancement of relief formation is defined as the efficiency of recording with extra illumination divided by efficiency without extra illumination. Diffraction efficiency and recording efficiency as well as relief formation enhancement provides only indirect information about changes of the surface relief depth, direct measurements of the surface relief profile was obtained by atomic force microscope (AFM).

The polarization state is defined by the plane where the electric field oscillates versus the *x*–*y* plane where both recording beams are located (see Fig. 1b). Therefore, if both planes have the same orientation this means that the light has a *p* or horizontal polarization state; otherwise, if both the planes are at an angle to each

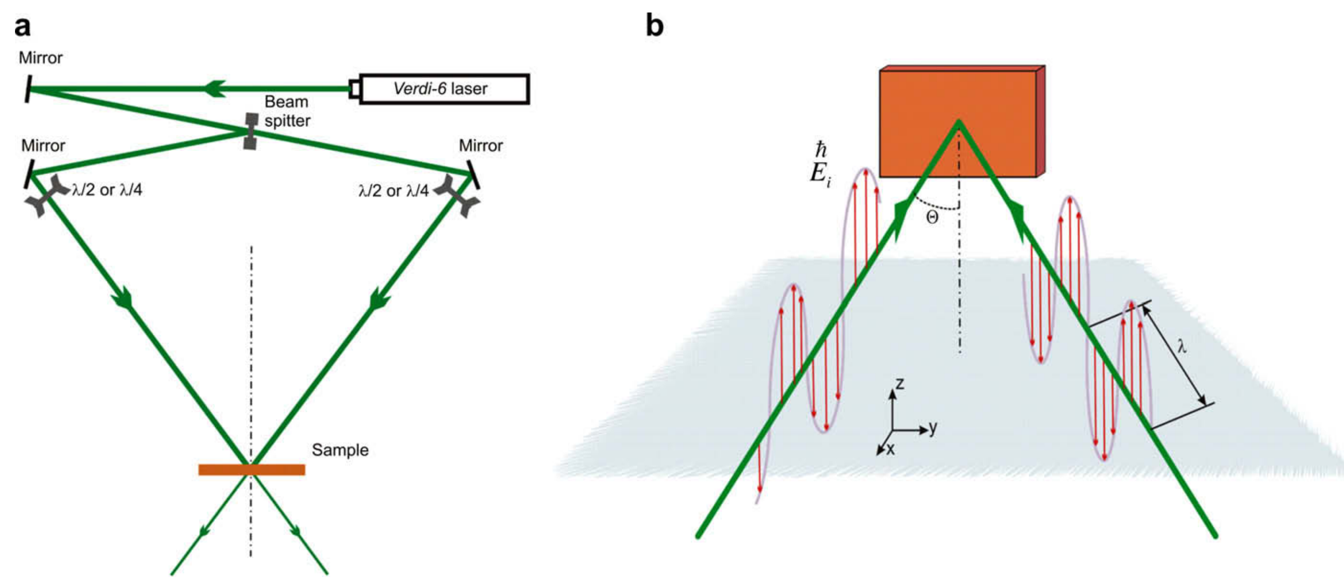

Fig. 1. (a) Experimental setup for holographic recording experiments; recording was performed by YAG *Verdi*-6 532 nm laser and (b) polarization is defined by the *x*–*y* plane where both recording beams are located – in this case both laser beams are vertically polarized, i.e. are in *s*-polarization state.

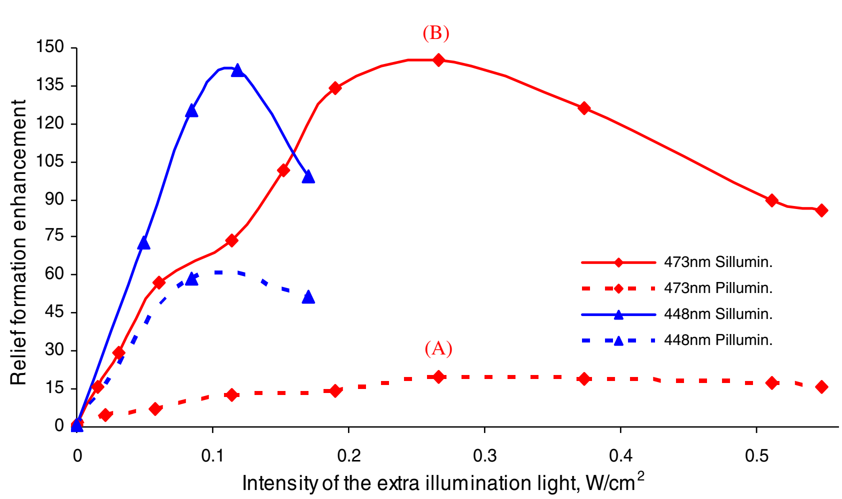

Fig. 2. Surface relief formation enhancement during holographic recording versus intensity of the extra illumination laser light (dots: experimental data) in the case of extra illumination at different wavelengths and polarization states of incoherent laser light (if $I_{extra} = 0$ the relief formation enhancement equals one). Recording was performed by *p*&*p*-polarized light on As_2S_3 sample by *Verdi*-6 532 nm (*p*-polarized) wavelength laser light where $I_1 = I_2 = 0.19$ Wcm^{-2} and period $\Lambda = 1$ μm.