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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

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GENERATION OF HOLOGRAPHIC GRATINGS ON AGFA EMULSION AND INVESTIGATION OF THEIR RELIEF STRUCTURE USING ATOMIC FORCE MICROSCOPY

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GENERATION OF HOLOGRAPHIC GRATINGS ON AGFA EMULSION AND INVESTIGATION OF THEIR RELIEF STRUCTURE USING ATOMIC FORCE MICROSCOPY

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ABSTRACT

Generation of holographic gratings on Agfa 8E56 HD photo emulsion layer is described and measurements on relief depth and diffraction efficiency of their profile structures using atomic force microscopy are presented.

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Preface

The ICTP-LAMP reports consist of manuscripts relevant to seminars and discussions held at ICTP in the field of Laser, Atomic and Molecular Physics (LAMP).

These reports aim at informing LAMP researchers on the activity carried out at ICTP in their field of interest, with the specific purpose of stimulating scientific contacts and collaboration of physicists from Third World Countries.

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INTRODUCTION

The generation of a surface relief on a silver halide emulsion has several applications such as production of holographic optical elements and display holograms. The embossing technique for mass replication of holograms utilizes the transfer of a relief pattern. The most eligible recording material for producing such master holograms is the photoresist material. This material exhibits, however, some disadvantages as having a rather low sensitivity and being sensitive only to UV and blue light. A silver halide emulsion, for instance Agfa-Gevaert 8E56 HD holographic plate, has the advantage of high sensitivity in any part of the visible spectrum. By applying a suitable chemical processing for development and bleaching of Agfa holographic plates, recording materials for embossing of master holograms can be produced employing inexpensive low-power lasers.

Using Kodak 649F emulsion, which is a thick and rather hard emulsion compared with the Agfa emulsion, pure relief images have been produced and a surface relief of about 1 μm has been observed [1-2]. The technique of obtaining relief structure on Agfa 8E56 HD photo emulsion was also tested for the recording of diffraction gratings with a fringe spacing of about 1 μm [3]. To investigate the profile of relief, the samples were coated and analysed using techniques of scanning electron microscopy. Other techniques for investigation of amplitude as well as phase holograms recorded on PE-2, Kodak and Agfa silver halide photo emulsion are also reported in literature [4-8].

After its invention and commercialisation, the atomic force microscopy (AFM) has become one of the most useful tools for visualisation and investigation of the elaborated surface structures [9-10]. The application of the AFM in the investigations of holographic gratings provides several advantages due to its practically use, producing easily the three dimensional view of the surface profile and especially not being needed for the sample to be an electrical conductor.

The main purpose of this work is to generate high quality holographic gratings for embossing of master holograms utilizing the features of the AMP as a new tool in holographic interfreometry. This is achieved mainly by the investigations of the surface morphology of photo emulsion plates carrying out precesion measurements on the relief height and spacing in terms of the optical parameters such as exposure time.

EXPERIMENTAL

The optical set-up used for recording diffraction gratings is the most common one as shown in Fig. 1. Two sets of gratings (labelled A and B), using the Agfa 8E56 HD photographic emulsion plates, were recorded at different inter-beam angles, namely at $2\theta = 10°$ and $22°$, respectively. For each set, five different exposures were made employing the argon ion laser line of 514.5 nm. The holograms were processed using the chemical composition developed originally for PE-2 photographic plates [4]. In order to prove the eligibility of this developer we measured the diffraction efficiency of the gratings, which is given by the basic equation

$$\eta = I_1 / I_0 \qquad (1)$$

where I_1 is the power in the first diffracted order and I_0 is the incident power after losses were subtracted due to reflections at the two surfaces.

The AFM used in the image acquisition is the TopoMetrix 2000 Explorer operating in contact mode. The force between the surface and pyramidal tip of the AFM has been minimized to exclude the material deformations creating extra surface features in consecutive scanning. The aspect ratio of pyramidal tip used is not vitally important for its height which is approximately ten times greater than the surface features. Totally, ten gratings (five for each set A and B) of photo emulsion plates have been scanned twice for each to discard some surface and tip artefacts. Two images collected for each relief have also been mathematically subtracted to observe the difference. Finally, in order to be sure about the surface profile of the sample that has been acquired during the first scan, scanning direction has been changed and reproducibility of the results has been confirmed.

RESULTS AND DISCUSSION

AFM is a very useful and easy way of providing high resolution images of gratings obtained by laser exposed photo emulsion surfaces. Fig. 2 shows blank surface of the plate used in this experiment. One can see the different spatial characteristics between Fig. 3a and 3b exposed with constant laser intensity ($I=60$ $\mu W/cm^2$) at $2\theta=10°$ for 1 and 5 seconds, respectively. Fig. 4a and 4b also show the difference at $2\theta = 22°$ with the same intensity and the same exposure times as in the case of set A. One can notify that the relief depths are decreasing as the exposure time increases for each recording angle, which is shown in Fig. 5. On the other hand, fringe spacing are still remained constant at about 1430 nm and 715 nm for the gratings of $2\theta=10°$ and 22°, respectively.

Utilizing the fact for thin phase holograms, the intensity of the radiation emitted in a given diffraction order is proportional to the phase difference, m/2, between the maximum and the minimum of a groove [4] as

$$I \propto J_q^2 \ (m / 2) \qquad (2)$$

where J is Bessel function of order q. The value of m/2 for a transmitting grating is related to the relief depth, L, as follows

$$m / 2 = \pi L (n - n_m) / \lambda \qquad (3)$$

where n and n_m are the refractive index of the grating material and of the surrounding material, respectively, and λ is the wavelength of the laser light illuminating the grating. The relief depth, L, is one of the key parameters to control the diffraction efficiency, if the other parameters in Eq. (3) are kept as experimental constants. It is therefore possible to associate easily the behavior of the relief depth (Fig. 5) and diffraction efficiency (Fig.6) versus exposure time. As seen from experimental results given in the last two figures, one can implicitly show that the trend of relief depth and diffraction efficiency trace the Bessel function.

Acknowledgement

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FIGURE CAPTIONS

Figure 1. Basic set-up for recording diffraction gratings; SF: spatial filter; CL: collimating lens; BS: beam splitter; M: plane mirror; HP: holographic plate; 2θ: inter-beam angle.

Figure 2. 3-D view of blank surface of the emulsion layer.

Figure 3. 3-D view of the samples exposed at $2\theta = 10°$ for 1 and 5 seconds, respectively.

Figure 4. 3-D view of the samples exposed at $2\theta = 22°$ for 1 and 5 seconds, respectively.

Figure 5. The change of relief depth with exposure time.

Figure 6. Diffraction efficiencies at Bragg angle versus exposure time.

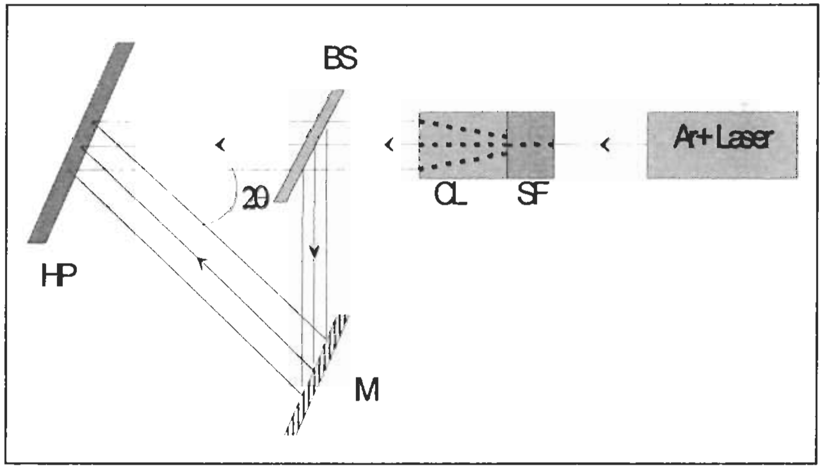


Fig.1

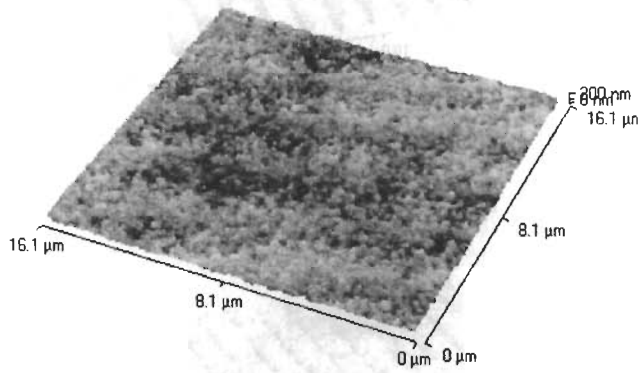
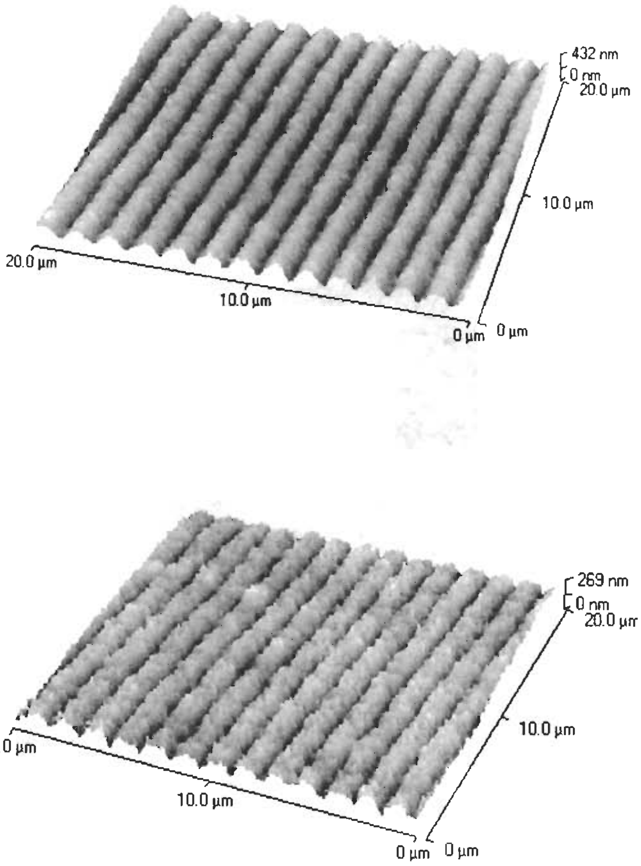


Fig.2

(a)

(b)



432 nm
0 nm
20.0 µm
10.0 µm
20.0 µm
10.0 µm
0 µm
0 µm
269 nm
0 nm
20.0 µm
10.0 µm
20.0 µm
10.0 µm
0 µm
0 µm

Fig.3

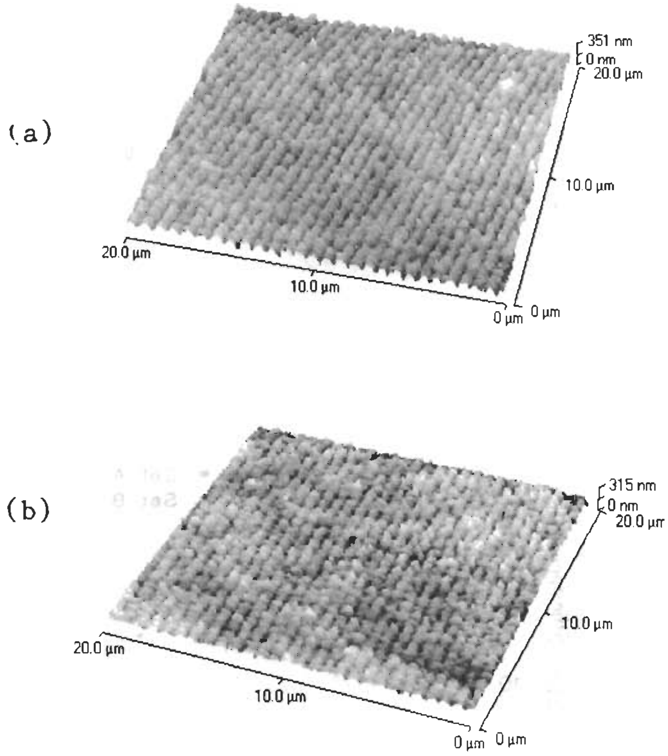

(a)
351 nm
0 nm
20.0 µm
10.0 µm
0 µm
20.0 µm
10.0 µm
0 µm
(b)
315 nm
0 nm
20.0 µm
10.0 µm
0 µm
20.0 µm
10.0 µm
0 µm

Fig.4

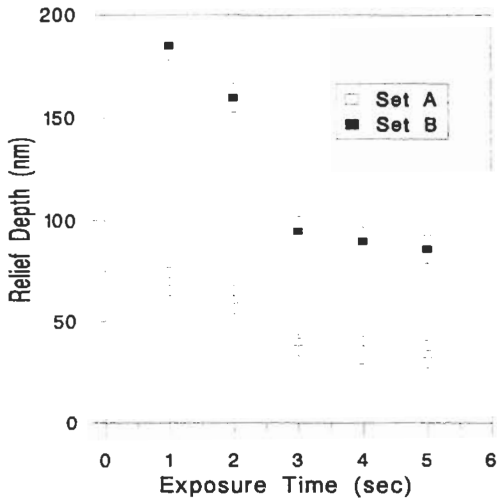

200
150
100
50
0
Relief Depth (nm)
Set A
Set B
0 1 2 3 4 5 6
Exposure Time (sec)

Fig.5

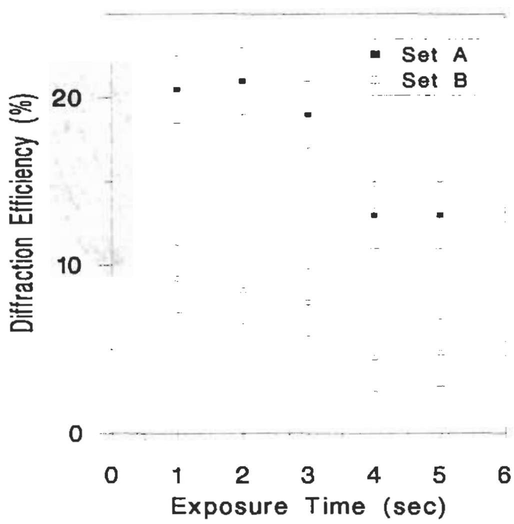

20
10
0
Diffraction Efficiency (%)
Set A
Set B
0 1 2 3 4 5 6
Exposure Time (sec)

Fig.6