Optica Applicata, Vol. XXI, No. 1, 1991

Amplitude and bleached phase holograms recorded and reconstructed at 442 nm

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The diffraction efficiency of amplitude and bleached phase holograms and scattering by bleached phase holograms have been measured using blue line of a He-Cd laser ($\lambda = 442$ nm). Kodak SO–253 film, Kodak 649F spectroscopic plates and Agfa–Gevaert 8E75 HD NAH plates were used. Five known bleaching agents were used to increase the diffraction efficiency and a maximum diffraction efficiency of approx. 38% has been achieved by using Agfa–Gevaert 8E75 HD NAH plates and ferric chloride plus concentrated sulphuric acid bleach phases.

1. Introduction

The maximum diffraction efficiency of amplitude holograms recorded on silver halide emulsion varies between 3.7% and 6.25%, where 6.25% is the theoretical maximum limit for thin hologram and 3.7% for thick hologram. Maximum diffraction efficiency of 100% may be obtained in the case of thick volume phase holograms [1], [2]. Due to an increase in scattering for the blue light, the diffraction efficiency of a hologram recorded and reconstructed at 442 nm is less than that of recorded and reconstructed under the same conditions at 632.8 nm. However, the diffraction efficiency of a hologram recorded at 442 nm is higher if it is reconstructed at 632.8 nm, instead of 442 nm [3]. Techniques for improving the diffraction efficiency by bleaching conventional absorption holograms, recorded as silver image, have been widely described in the literature [3]–[16]. The purpose of the bleach techniques is to convert the photographic silver image into a transparent compound with refractive index different from that of the gelatin, resulting in phase holograms with a considerably higher, maximum diffraction efficiency.

In the present paper, we have investigated the influence of five known bleach processes on the diffraction efficiency and scattering in converting a silver image into a corresponding dielectric image. The purpose of the present paper is to standardize the bleaching agents and recording material for recording colour holograms with high diffraction efficiency, when the three primary colour (red, green and blue) radiations have to be used. If two holograms are recorded in the same emulsion, the available dynamic range is shared between the recordings, and maximum diffraction efficiency of each recording is cut by a factor of almost 4. Multiplexing three holograms on the same plate results in a cut in the maximum diffraction effi-

ciency by a factor close to 9. Hence, either any one or both the techniques (the sandwich and bleaching) may be used to increase the maximum diffraction efficiency of the colour holograms [11].

2. Experimental procedure

Diffraction gratings were recorded on Kodak SO–253 film, Kodak spectroscopic type 649 F plates and Agfa–Gevaert 8E75 HD NAH plates, by the method of the interference of two plane waves (cross section diameter approx. 1.5 cm) of equal intensity illuminating the plate from the same side. As shown in Fig. 1**a**, the angle between the two beams was approx. 20°, corresponding to a spatial frequency of approx. 780 cycles/mm and both the beams were incident on the plate making equal angles to the normal on the plate. 442 nm radiation was used from a 50 mW He-Cd

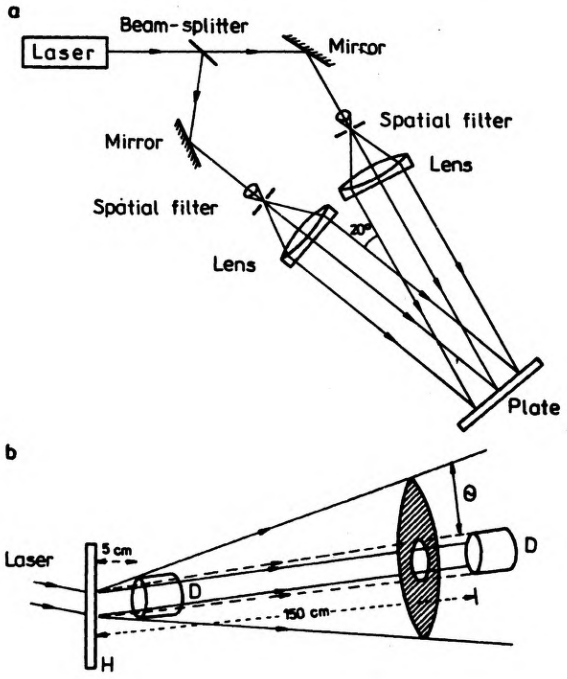

Fig. 1. Setup for recording the interference gratings (**a**), and setup for reconstruting the hologram and measuring the diffracted scattered intensities (**b**). **H** – hologram, D – detector, θ – angle for which scattering has been measured

laser (Omnichrome, Model No. 4112). Sets of gratings varying the exposure were processed and bleached using different bleaching agents (Table 1).

As shown in Figure 1**b**, the hologram was reconstructed to measure the diffracted and scattered intensities, by placing it so as to satisfy the Bragg condition. A 3.5 mm diameter collimated beam was used to reconstruct the hologram and diffracted and

scattered intensities were measured. The diameter of the reconstructing beam was very small as compared to the diameter of the recording beam, and the

Table 1. Processing schedule

1.	Expose*
2.	Develop in Kodak D–19 developer for 5 minutes*
3.	Wash in distilled water for 2 minutes*
4.	Fix in sodium thiosulphate solution for 4 minutes*
5.	Wash in distilled water for 2 minutes (bleached holograms) or 5 minutes (amplitude holograms)*
6.	Bleach (Table 2)
7.	Wash in running water for 5 minutes
8.	Dry:** i) Rinse in methyl alcohol for 1 minute
	ii) Rinse in isopropyl alcohol for 1 minute
	iii) Dry with jet of hot air

* Indicates that the step was used for amplitude holograms also.

** Special precautions should be taken in this step, beacuse the efficiency is very much dependent on drying procedure [12].

Note: Temperature of all the baths was taken $20 \pm 0.5°C$

diffraction efficiency at the centre of the hologram was taken as the efficiency of that hologram.

Measurements were made for the diffraction efficiency and scattering of these gratings. The diffraction efficiency η is defined here by the relation $\eta = I_d/I_i$, where I_d is the power in the first diffracted order at the Bragg angle and I_i is the incident power on the plate/film. The scattering in bleached phase holograms was assessed indirectly by means of a difference measurement. The power diffracted into the first order has been measured, at a distance of 5 cm from the plate and at a distance of 150 cm from the plate and the difference of the two was termed scatter. In this way, the cone for angle θ ($\sim 4.6°$), for which the scattering has been measured, is shown in Fig. 1**b** by the shaded region.

3. Results and discussion

The diffraction efficiency of amplitude holograms, and the influence of five known bleach processes on the diffraction efficiency and scattering of the bleached phase holograms, recorded and reconstructed at 442 nm on the three types of silver halide recording materials (Kodak SO–253 film, Kodak 649F spectroscopic plates and Agfa–Gevaert 8E75 HD NAH plates), have been evaluated using the bleach processes given in Table 2.

Figure 2 shows the variation of diffraction efficiency of amplitude holograms as a function of exposure (relative unit) for the above mentioned three types of silver halide recording materials. Figures 3–5 show the variation of the diffraction efficiency as a function of exposure (relative unit) of the bleached phase holograms

Table 2. Bleaches with bleaching time

Bleaches	Procedure	Bleachting time [min]
Br_2-vapour bleach [8]	Bleach and put the plate in room for overnight	30–40
Ferric chloride bleach [6], [7] (70 g ferric chloride + 4.0 cm^3 concentrated sulphuric acid + 1.0 dm^3 distilled water)	Bleach the platte for 20 s after the plate cleared	1.5–4.0
Ferric nitrate and potassium bromide bleach [6], [7] (45 g ferric nitrate + 48 g potassium bromide + 4 cm^3 concentrated sulphuric acid + 1.0 dm^3 distilled water)	Bleach the plate for 20 s after the plate has cleared	1.5–4.0
Potassium iodide and iodide bleach [6], [7] (15 g potassium iodide + 1 g iodide + 1.0 dm^3 distilled water)	Bleach the plate for 1 min. after the plate has cleared	5–10
Potassium ferricyanide and potassium bromide bleach [4] (7 g potassium bromide + 8 g potassium ferricyanide + 1.0 dm^3 distalled water)	Bleach the plate for 1 min. after the plate has cleared	4–8

recorded on Kodak SO–253 film, Kodak 649F spectroscopic plates and Agfa–Gevaert 8E75 HD NAH plates respectively. Figures 6–8 show the variation of scattering as a function of exposure (relative unit) of the bleached phase holograms recorded on the above mentioned three type of recording film/plates, respectively. Good diffraction efficiency has been observed by using Agfa–Gevaert 8E75 HD NAH plates with all the five bleach processes in comparison to other plates/film used. A maximum diffraction efficiency of 2% has been observed from amplitude holograms by using Agfa–Gevaert 8E75 HD NAH plates. A maximum diffraction efficiency of approx. 38% has been achieved by using Agfa–Gevaert 8E75 HD NAH plates with ferric chloride plus concentrated sulphuric acid bleach process. In comparison to other bleach processes and recording plates/film, low scattering with maximum diffraction efficiency has been observed by using Kodak 649F spectroscopic plates with potassium ferricyanide and potassium bromide bleach process. Using Kodak SO–253 film, poor diffraction efficiency and low scattering have been observed. The present paper does not characterize the recording material in general beacuse very good diffraction efficiency has been observed on Kodak SO–253 film using 632.8 nm radiation (results are not related to this paper).

4. Conclusions

Diffraction efficiency and scattering as a function of exposure (relative unit) have

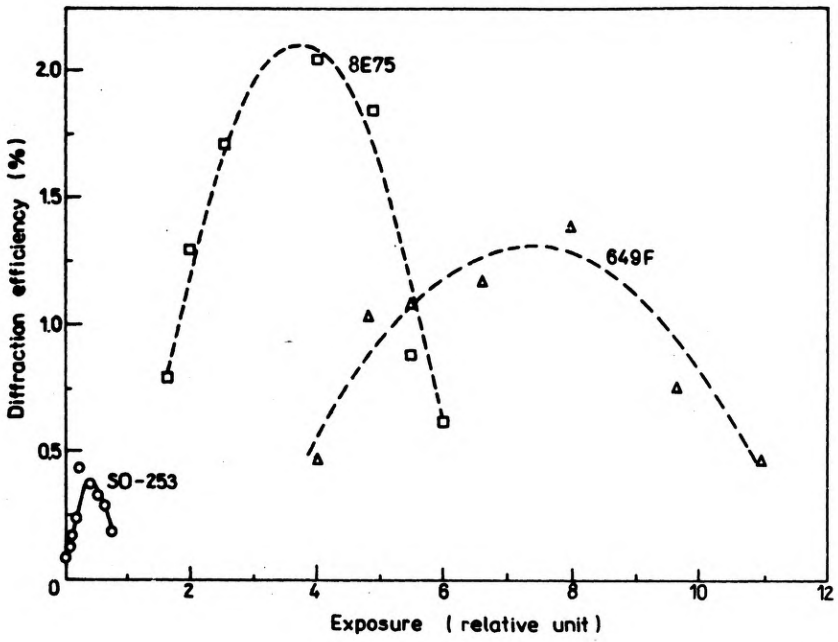

Fig. 2. Variation of the diffraction efficiency with exposure for the amplitude holograms recorded on Kodak SO–253 film (●——●), Kodak 649F spectroscopic plates (△---△), and Agfa–Gevaert 8E75 HD NAH plates (□---□)

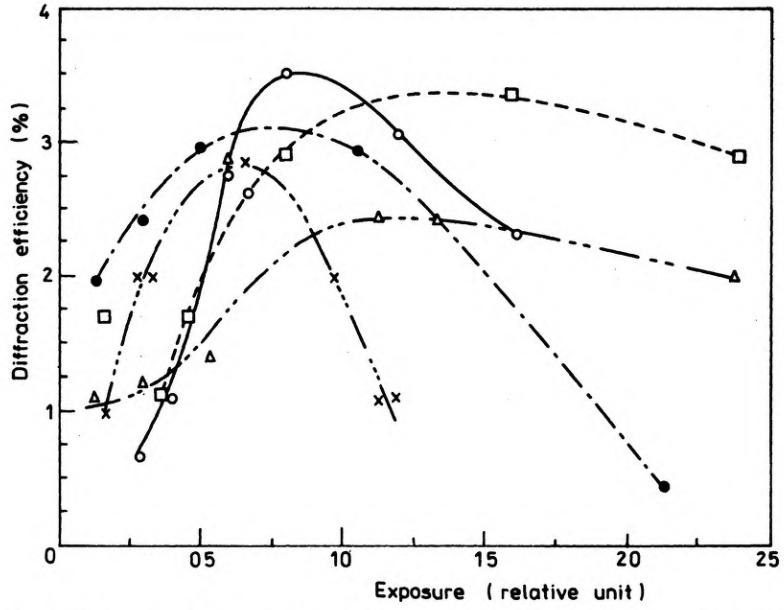

Fig. 3. Varivtion of the diffraction efficiency with exposure for the bleached phase holograms recorded on Kodak SO–253 film using the following bleach processes: Br_2 – vapour bleach (△----△), ferric chloride bleach (o---o), ferric nitrate and postassium bromide bleach (●---●), potassium iodide and bleach (×-----×), and potassium ferricyanide and potassium bromide bleach (□---□)

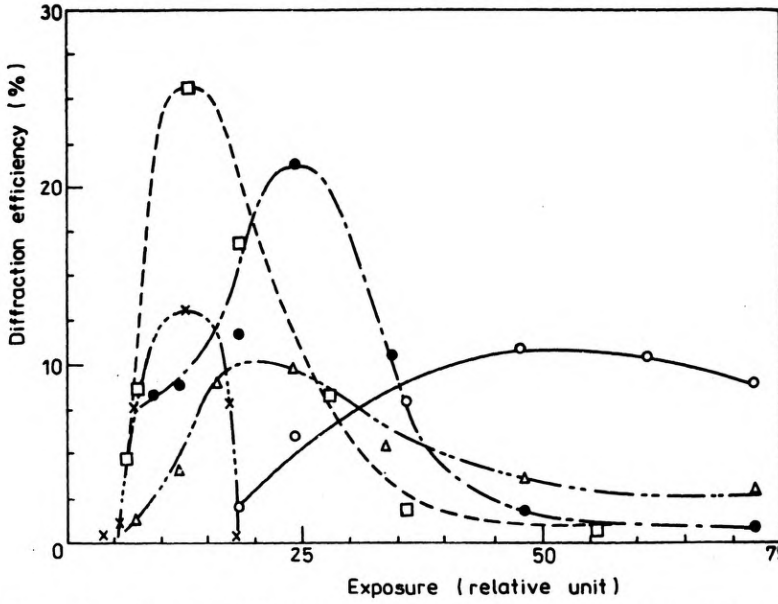

Fig. 4. Variation of the diffraction efficiency with exposure for the bleached phase holograms recorded on Kodak 649F spectroscopic plates using the bleaches as in Fig. 3

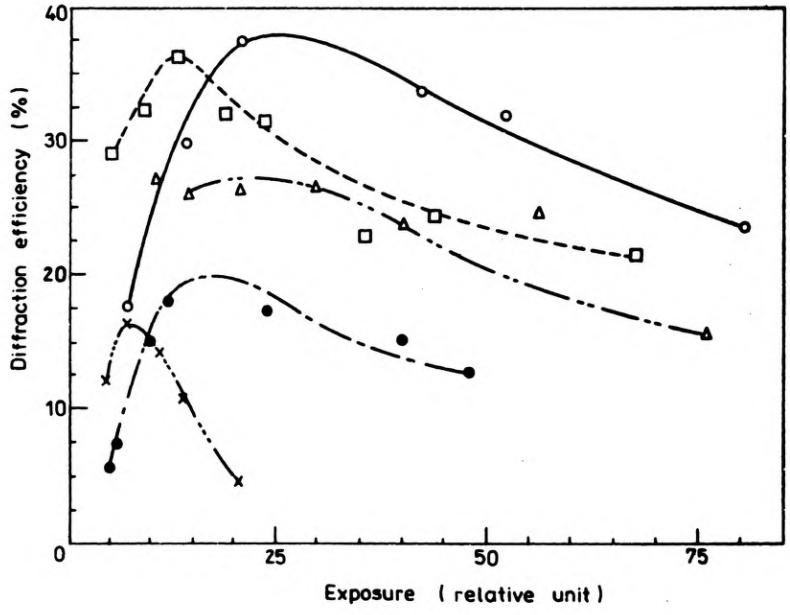

Fig. 5. Variation of diffraction efficiency with exposure for the bleached phase holograms recorded on Agfa–Gevaert 8E75 HD NAH plates using the bleaches and in Fig. 3.

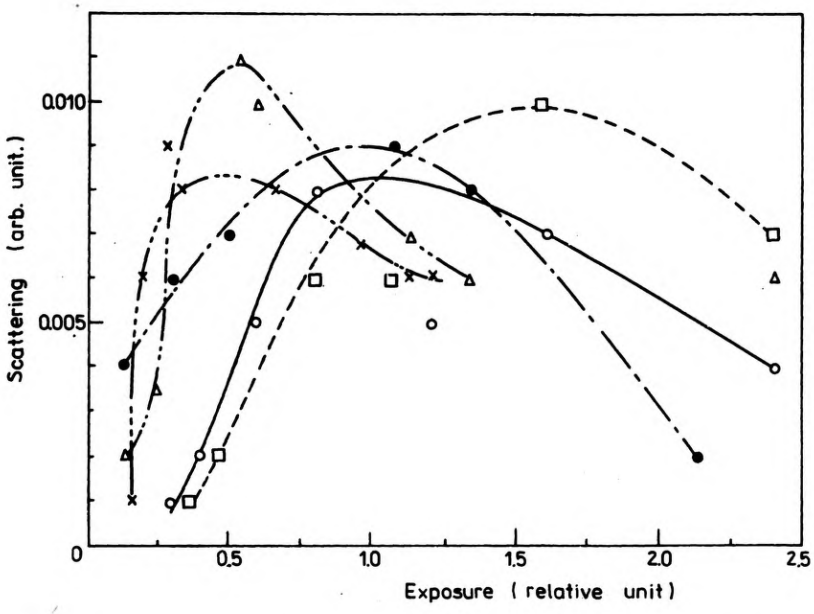

Fig. 6. Variations of scattering with exposure for the bleached phase holograms recorded on Kodak SO–253 film using the bleaches as in Fig. 3

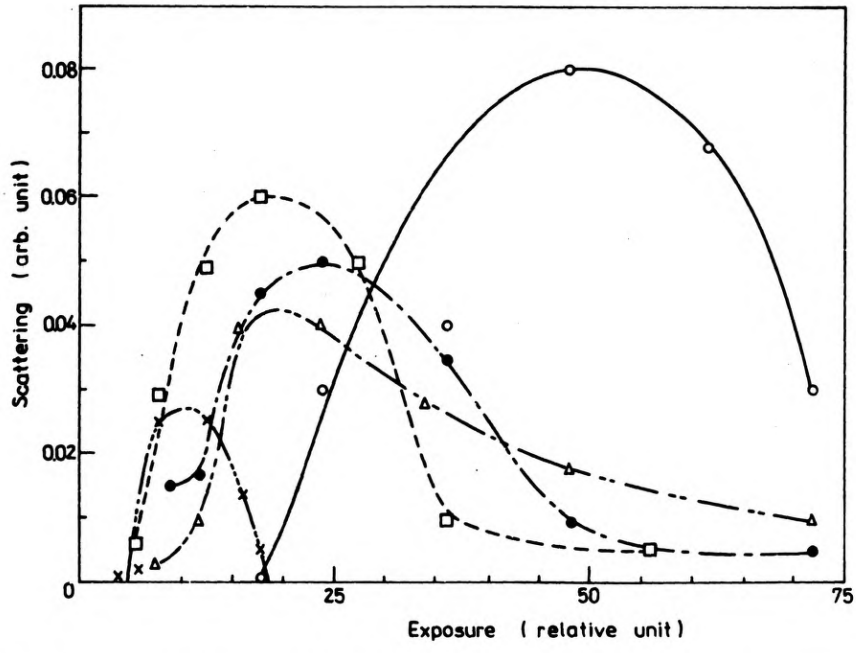

Fig. 7. Variation of scattering with exposure for the bleached phase holograms recorded on Kodak 649F spectroscopic plates using the bleaches as in Fig. 3

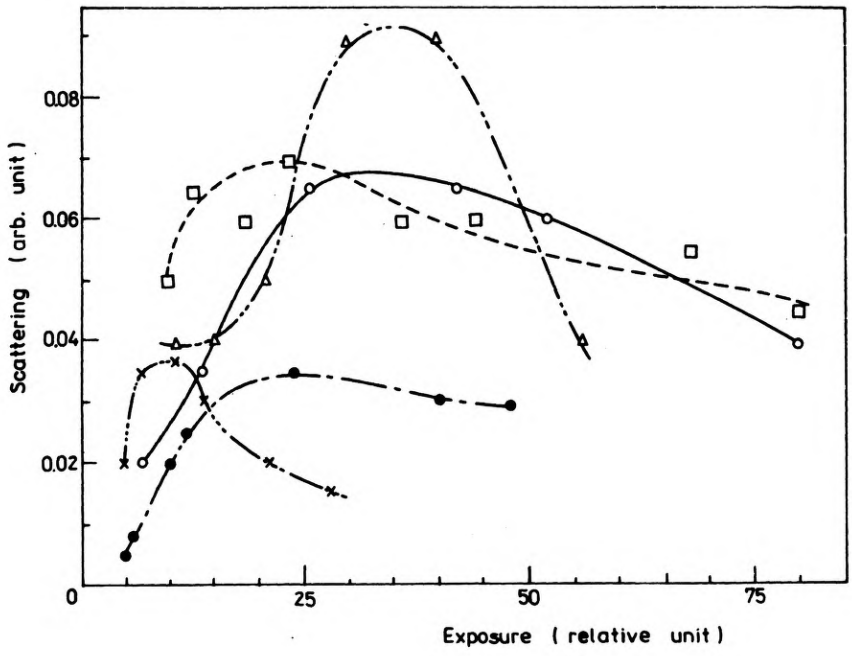

Fig. 8. Variation of scattering with exposure for the bleached phase holograms recorded on Agfa–Gevaert 8E75 HD NAH plates using the bleaches as in Fig. 3

been evaluated using three types of silver halide recording plates/film and five known bleach processes. Of the three plates/film used, Agfa–Gevaert 8E75 HD NAH plates show maximum diffraction efficiency for both, amplitude and phase holograms. A maximum diffraction efficiency of approx. 38% of the bleached phase holograms has been achieved by using ferric chloride plus concentrated sulphuric acid bleach process. Kodak 649F spectroscopic plates show good diffraction efficiency with potassium ferricyanide and potassium bromide bleach process. Potassium ferricyanide and potassium bromide bleach process is considered best for good diffraction efficiency with low scattering for both Agfa–Gevaert 8E75 HD NSH and Kodak spectroscopic type 649 plates.

Acknowledgements – This work was partially supported by the Ministry of Human Resource Development, Government of India, under trust area programme on *Holography, Image Processing and Laser Speckles*. A part of the work was carried out under a project on *Holographic Displays* sponsored by the Department of Science and Technology, Government of India.

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Received March 8, 1991

Амплитудные голограммы и фазовые отбеливатели регистрированные и реконструированные при 442 nm

Выполнены измерения дифракционной эффективности амплитудных голограмм и фазовых отбеливателей, а также рассеивания на отбеливаемых фазовых голограммах, употребляя линию He-Cd ($\lambda = 442$ nm). Применялись пленки Кодак SO–253, спектроскопические пластинки Кодак 649F, а также пластинки Агфа–Геверт 8E75 HD NAH. Применили пять известных отбеливающих реактивов для повышения дифракционной эффективности; достигли максимальной эффективности ок. 38% при применении пластинок Агфа–Геверт 8E75 и треххлористого железа, а также купоросного масла в процессе отбеливания.

Перевел Станислав Ганцаж