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Bleached phase holograms produced by fixation-free methods for low scattering using Agfa–Gevaert 10E75 NAH plates

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An experimental study has been made of the diffraction efficiency, scattering and the stability against printout effect, of the bleached, photographically recorded two-beam interference gratings using Agfa–Gevaert 10E75 NAH plates. The efficiency is increased by using four known bleaching processes suitable for fixation-free methods. Plots of the diffraction efficiency and scattering as a function of exposure are given. Variation of the maximum diffraction efficiency of the holograms is shown as a function of the departure from the Bragg angle, and exposure to white light for various bleach processes with two developers. A maximum diffraction efficiency of approximately 28% has been achieved by using potassium dichromate plus concentrated sulphuric acid and potassium iodide bleach process.

1. Introduction

Among the various light sensitive recording media, the most widely used in holography are silver halide photographic materials, out of which Agfa–Gevaert 10E75 is preferred [1]–[7] for recording thick transmission holograms due to its higher sensitivity for red light of the He-Ne or ruby laser. In order to obtain the phase hologram, an exposed emulsion is chemically processed and bleached. In a direct bleach process, the photographic silver image is converted into a transparent compound with refractive index different from that of the gelatin, resulting in a phase hologram with a considerably higher, maximum diffraction efficiency [1]–[16]. Unfortunately, the reconstructed image quality tends to be degraded by an increase of scattered light. To overcome this drawback, another procedure of bleaching using fixation-free methods has been widely reported in the literature [10]–[22].

In the reversal bleach technique [10], [20], [21], the emulsion is developed as in the direct bleaching process, but instead of dissolving away the undeveloped silver halide it is the silver image that is removed. However, as this process removes a significant amount of material from the emulsion, it is sometimes desirable when using reversal bleach baths, to use a tanning developer. This helps limit emulsion shrinkage. In this paper, we report the results of an extensive study of the diffraction efficiency, scattering and stability against the printout effect with various types of developers and four known bleach processes, to select the best combination of the developer and bleaching procedure for the Agfa–Gevaert 10E75 NAH plates. The motivation for such a study is to standardize the fast developing baths and bleach processes for producing holograms with low noise level using high sensitivity emulsion.

2. Experimental procedure

Diffraction gratings by the method of the interference of two plane waves of equal intensity were recorded on Agfa–Gevaert 10E75 NAH plates, using 632.8 nm radiation from a 15 mw He-Ne laser. The angle between the two beams was approximately 45° corresponding to a spatial frequency of about 1200 cycles/mm, and both the beams were incident on the photographic plate making equal angles to the normal on the plate (see Fig. 1a). The diameter of both the beams was

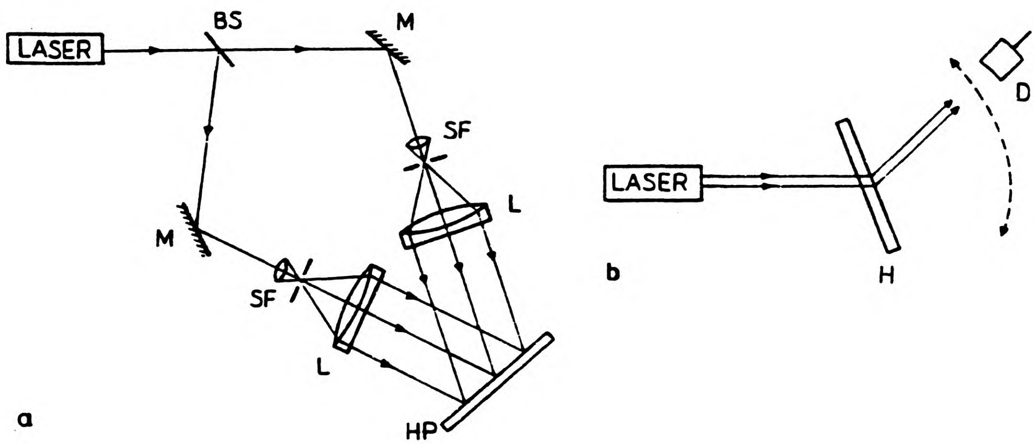

Fig. 1. Setup for recording the interference gratings (a), and setup for reconstructing the holograms and to measure the diffracted and scattered intensities (b). BS – beam splitter, M – mirror, SF – spatial filter, L – lens, HP – holographic plates, H – holograms, D – detector

approximately 2.5 cm. Sets of gratings varying the exposure were processed (see Tab. 1 and 2) and bleached using different bleaching agents.

The hologram was reconstructed to measure the diffracted and scattered intensities, by placing it so as to satisfy the Bragg condition (see Fig. 1b). A 3 mm diameter collimated beam was used to reconstruct the holograms. The diameter of the reconstructing beam was very small compared to the diameter of the recording beam, and the efficiency at the centre of the processed hologram was taken as the efficiency of that hologram.

Measurements were made of the diffraction efficiency η, scattering and the stability against the printout effect of the gratings. The diffraction efficiency is

Table 1. Processing schedule

1. Expose
2. Develop (see Tab. 2)
3. Wash in distilled water for 2 minutes
4. Bleach ([12]–[14], [17]–[19], with slight modifications in time for bleaches 1 and 2)
5. Wash in running water for 5 minutes
6. Dry*
   i) dry the plate in calm atmosphere at room temperature, or
   ii) rinse in methyl alcohol for 1 min
   iii) rinse in isopropyl alcohol for 1 min
   iv) use cool air jet to dry

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

Note: Temperature of all the baths was approximately the same as for the developing bath.

Table 2. Developer with developing time and temperature

Developer	Developing time (min)	Bath temperature (°C)
IPC* 163 (equivalent of Kodak DA 163) diluted 1:5 in distilled water	3	20±0.5
CW–C2 [18]	2	20±0.5
Kodak special developer**, SD–48, concentrated of diluted 1:2 or 1:5 or 1:10 in distilled water	2	24±05

* India Photographic Co. Ltd. (Kodak affiliate).
** Prepared according to the composition reported in [21].

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 less losses due to reflection at two surfaces and absorption in the glass of plate, i.e., incident power on the grating emulsion.

The scattering in bleached holograms was assessed indirectly by means of a difference measurement [8]. The power diverted into the zero order, all diffracted orders and film absorption in an unexposed region on the plate was subtracted from the incident light beam falling on the grating emulsion; and the residual, unaccounted for light was termed scatter.

Variation of the maximum diffraction efficiency of the holograms as a function of the departure from the Bragg angle has been measured. A white light beam from a 100 W spot lamp was used to study the printout effect. The distance between the hologram and the lamp was approximately 10 cm. The variation of the maximum diffraction efficiency of the holograms as a function of the exposure time (in hours) has also been measured.

3. Results and discussion

Diffraction efficiency, scattering and the stability against the printout effect of the phase holograms produced by four bleaching processes using fixation-free methods with three different types of developers have been studied. In total nine combinations of developers with bleach processes have been studied.

The four known bleaching agents used here are: 1) potassium dichromate plus concentrated sulphuric acid [12]–[14], 2) potassium dichromate plus concentrated sulphuric acid and potassium iodide [17], [19], 3) PBQ–1 [18], and 4) PBQ–2 [18]. Figures 2 and 3 show the plots for the diffraction efficiency η as a function of exposure

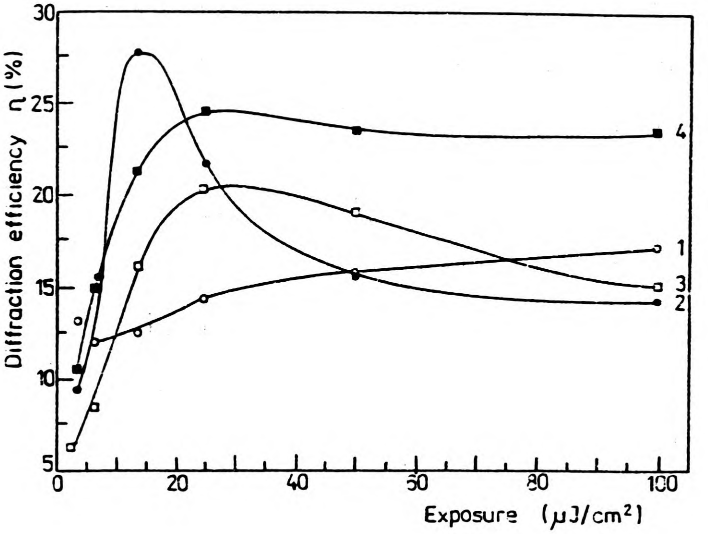

Fig. 2. Variations of the diffraction efficiency with exposure for photographic phase gratings produced with ICP 163 developer and the bleaches 1, 2, 3 and 4

for the developers IPC 163 and CW–C2, respectively. Figures 4 and 5 show the plots for the scattering as a function of exposure for the developers IPC 163 and CW–C2, respectively. Figures 6 and 7 show the plots for the variation of the maximum diffraction efficiency of the processed holograms as a function of the departure from the Bragg angle for the developers IPC 163 and CW–C2, respectively. Figures 8 and 9 show the plots for the variation of the maximum diffraction efficiency of the holograms as a function of the exposure time (in hours) in white light for the developers IPC 163 and CW–C2, respectively.

Departure from the Bragg angle for the first minimum of the diffraction efficiency varies from 10 to 18 degrees. Its values are: 13 deg. for potassium dichromate plus concentrated sulphuric acid and potassium iodide, 12 deg. for potassium dichromate and concentrated sulphuric acid, 11 deg. for PBQ–2 and 10 deg. for PBQ–1 with IPC 163 developer and 12 deg. for PBQ–2 and potassium dichromate and concentrated

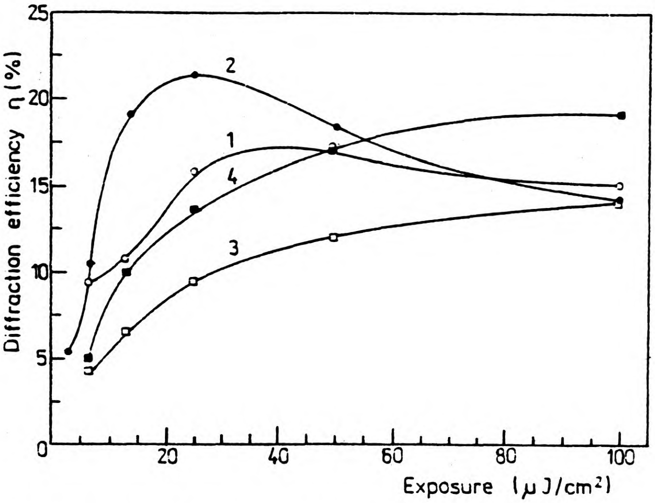

Fig. 3. Same as in Fig. 2, but with CW-2 developer

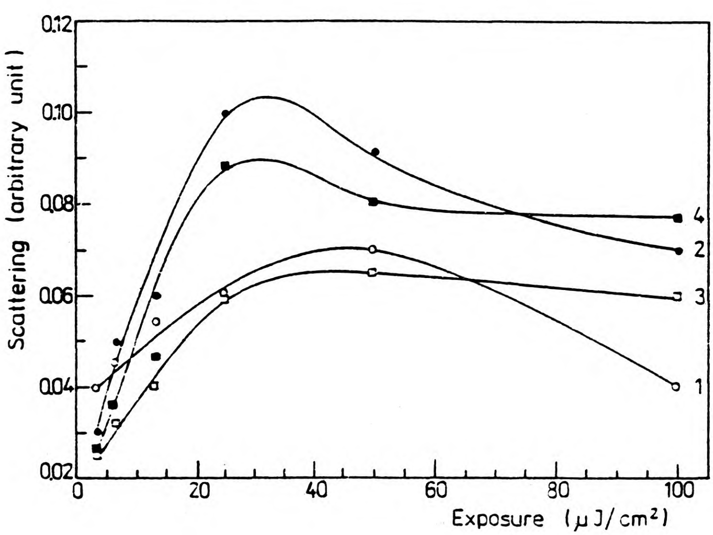

Fig. 4. Variations of scattering with exposure for photographic phase gratings produced with ICP 163 developer and the bleaches 1, 2, 3 and 4

sulphuric acid, 11 deg. for potassium dichromate plus concentrated sulphuric acid and potassium iodide and 18 deg. for PBQ–1 with CW–C2 developer, respectively.

In case of Kodak special developer SD–48, a set of gratings was developed in the following manner. A piece of plate was exposed and developed in the Kodak special developer SD–48 at 24° C and bleached with potassium dichromate and concentrated sulphuric acid. This hologram was found to give poor reults. Then three pieces of plates were given the same exposure and developed in the diluted baths, 1:2, 1:5 and 1:10 in distilled water, respectively, and subsequently bleached. The hologram developed in 1:5 diluted developer (mentioned above) shows results better than the other diluted baths when it was developed for 2 min. Then a set was exposed and developed in the Kodak special developer diluted 1:5 in distilled water

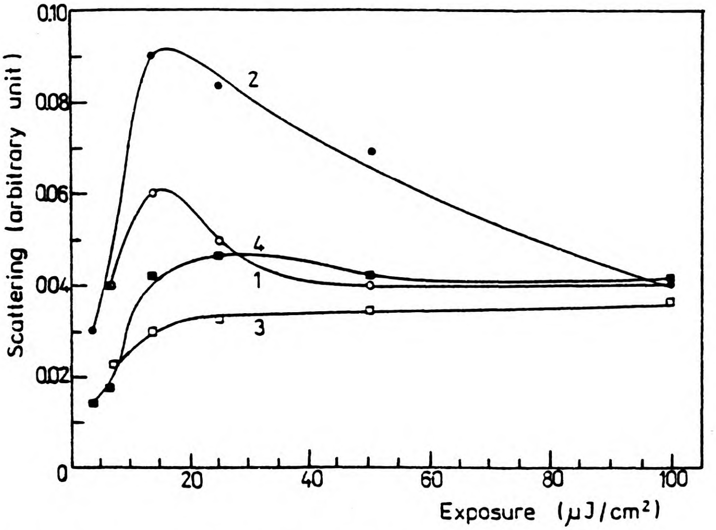

Fig. 5. Same as in Fig. 4, but with CW–C2 developer

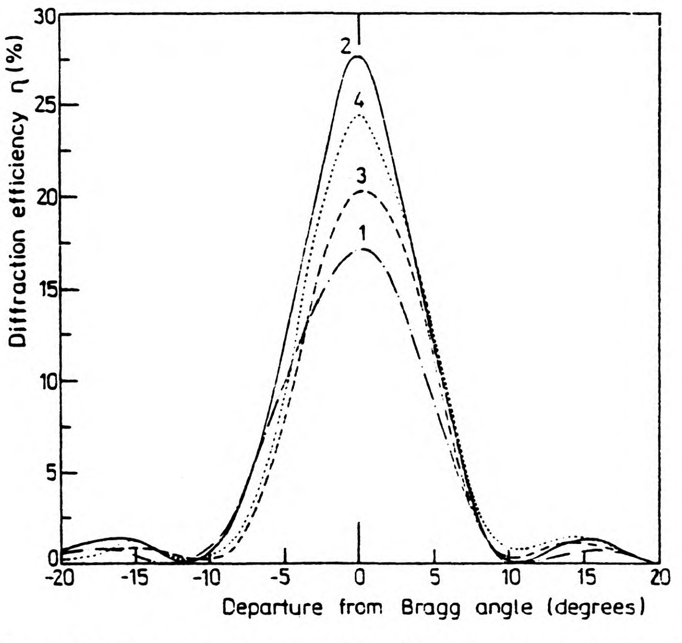

Fig. 6. Variation of the maximum diffraction efficiency as a function of departure from the Bragg angle of the holograms produced with ICP 163 developer and the bleaches 1, 2, 3 and 4

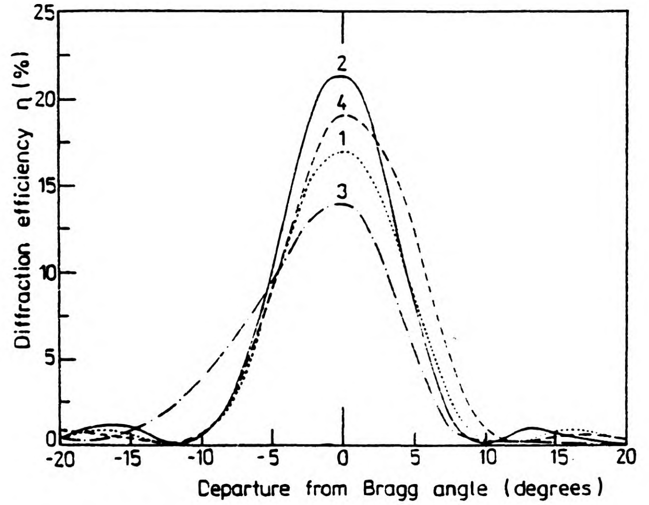

Fig. 7. Same as in Fig. 6, but with CW–C2 developer

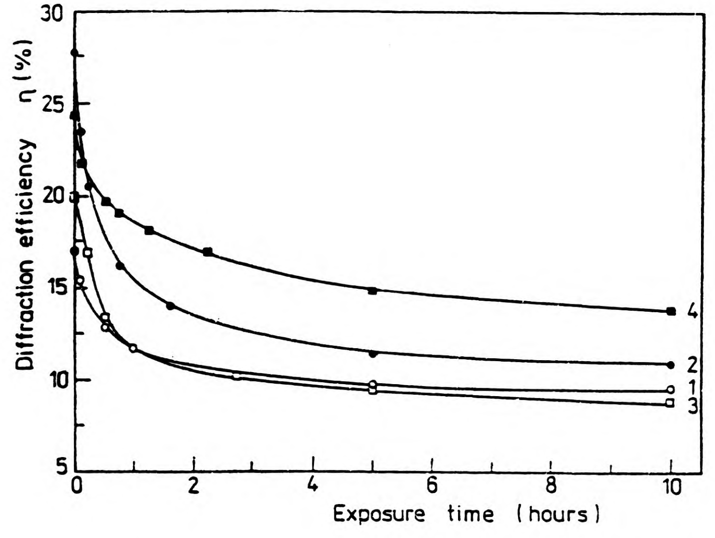

Fig. 8. Variation of the maximum diffraction efficiency as a function of exposure time (in hours) in white light of the holograms produced with ICP 163 developer and the bleaches 1, 2, 3 and 4

and bleached with the same bleaching materials. The results observed were not satisfactory in comparison to the other combinations studied. Due to poor diffraction efficiency and image quality we have not plotted the curves. A maximum diffraction efficiency of 8% was achieved by using this combination.

Recently, HARIHARAN et al. [9], [14] have reported results relating to diffraction efficiency and scattering using different bleaches, and developers and developer compositions. We have also investigated [5]–[7] various bleaches and the influence of different developers and developer compositions on diffraction efficiency, scattering and stability in bleached phase holograms. The curves for variation of diffraction efficiency show a trend similar to results in papers [5], [6], [9] and [14]. However, the results for variation of scattering are not similar to those reported in above references. The variation in diffraction efficiency and scattering, for the holograms produced by fixation-free methods is slow over a wide range of exposures in comparison to conventional bleaches [5], [6], [14], where fixation is used.

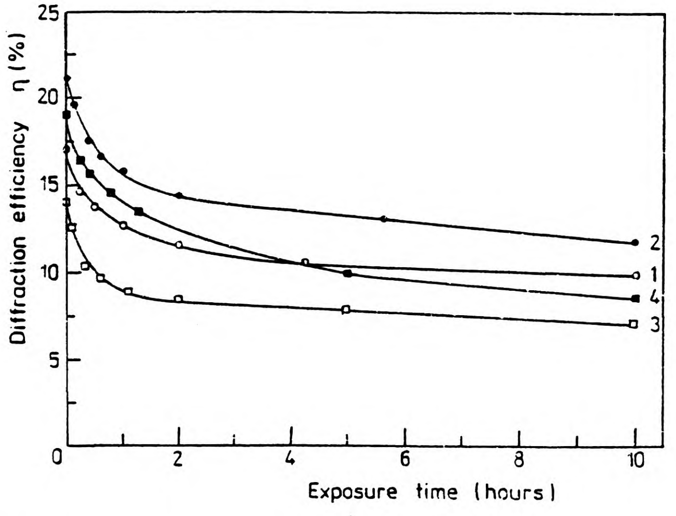

Fig. 9. Same as in Fig. 8, but with CW–C2 developer

Though the maximum stability against the printout effect was observed by using potassium dichromate and concentrated sulphuric acid bleach with IPC 163 and CW–C2 developers, good results were observed by using PBQ–2 bleach process with IPC 163 and CW–C2 developers and potassium dichromate plus concentrated sulphuric acid and potassium iodide bleach process with IPC 163 developer.

4. Conclusions

Of the nine combinations used, the developer IPC 163 and bleach process potassium dichromate plus concentrated sulphuric acid and potassium iodide combination is considered good for low exposures ranging from 10 $\mu J/cm^2$ to 22 $\mu J/cm^2$, because at low exposures it shows maximum efficiency of approximately 28% and good image quality; while at higher exposures and for a wide range of exposures ranging from 25 $\mu J/cm^2$ to 100 $\mu J/cm^2$, the combination of developer CW–C2 and bleach process PBQ–2 is considered good for higher diffraction efficiency and good image quality.

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