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Influence of different developers and bleach processes on diffraction efficiency and scattering of holograms

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A comparative study has been made of both the diffraction efficiency and scattering of bleached holograms recorded on Kodak 649F plates by using a pulsed Nd:YAG laser at 532 nm (second harmonic) wavelength, as a function of exposure. Seven known developers and five known bleach processes have been used. The results are presented in graphical form. A maximum diffraction efficiency of about 45 percent has been achieved using Kodak HRP developer and ferric chloride plus concentrated sulphuric acid bleach process.

1. Introduction

Silver halide photographic emulsions continue to be an important recording medium in holography. This is due to their high sensitivity, easy commercial availability, and improved new processing techniques. High sensitivity of photographic emulsions helps to make hologram formation with human objects safer using pulsed laser [1]. However, use of a pulsed laser does not lessen the need for recording material of high sensitivity and resolution, *etc.*, [1]. Processing is approximately similar to the processing of the holograms recorded with continuous wave laser. However, the characteristics of the silver halide photographic material show different behaviour [2]–[5]. The gamma is much less and post exposure was not found useful in obtaining short-exposure holograms. However, the increased development time was found to increase significantly the speed and gamma without noticeably increasing the fog.

There are various bleach techniques available [1], [5]–[16], for obtaining phase holograms using silver halide photographic emulsions. Direct bleaching is the process mostly used for transmission holograms. This technique produces holograms of very high diffraction efficiency (DE). However, the image quality is degraded due to enhanced scattering. Therefore, standardization of different developers and bleach processes is always required for producing holograms of high efficiency and low scattering.

Recently, we have investigated the influence of various known developers and known bleach processes on the DE, scattering and stability against printout effect [17]–[20], and stability against relative humidity [21] variations of the atmosphere, where the hologram is displayed. In addition, studies have been made at 442 nm wavelength [22]–[24], for standardizing the bleaching technique and processing

method for producing colour holograms, where the three primary colour (red, green and blue) radiations have to be used simultaneously.

In various holographic applications, it is either necessary or desirable to record a holographic optical element (HOE) at a wavelength that is different from the one at which the HOE is to be used. The serious degradation in aberration performance due to wavelength change and its reduction is reported in the literature. In addition to this, the DE and scattering may increase or decrease significantly.

In this paper, we report our results of investigations made on the variation of the DE and scattering as a function of exposure (relative units) of the bleached holograms recorded at 532 nm and reconstructed at 633 nm and 514 nm wavelengths. The motivation of the present comparative study is to make available the results which may be useful in such applications such as making of direct vision spectroscope, holographic microscope, display holography, and holographic optical elements.

2. Experimental procedure

The experimental setup made use of a Newport research series table, a Nd:YAG pulsed laser (532 nm, second harmonic), a He-Ne laser, an Ar^+ laser at 514 nm and optical components, *etc.* Transmission holographic gratings were recorded on Kodak 649F plates using two equal intensity laser beams from a pulsed Nd:YAG laser at 532 nm wavelength. The angle between the beams was approximately 20° corresponding to a spatial frequency of about 1000 cycles/mm. The processing of the holograms was similar to our earlier papers [22]–[23] and need not be repeated here. In addition to this, reconstructions of the holograms were made in a manner similar to our earlier papers [22], [23] using 633 nm and 514 nm wavelengths.

The developers used here are: 1. Kodak D-19. 2. Kodak HRP. 3. IPC 163 (equivalent of Kodak DA 163). 4. IPC 76. 5. Ascorbic acid [18]. 6. CW-C1 [25]. 7. CW-C2 [25].

The bleach processes used are: 1. Potassium ferricyanide and potassium bromide [7]. 2. Ferric nitrate plus potasium bromide [8]. 3. Ferric chloride plus concentrated sulphuric acid [8]. 4. Potassium iodine and iodine [8]. 5. Potassium dichromate plus potassium bromide [9], [10].

3. Results and discussion

The holograms were recorded at 532 nm, while reconstructed – at 514 nm and 633 nm wavelengths. 633 nm wavelength was used to see the effect of wavelength change. However, 514 nm was used as it is available in continuous form and is near to 532 nm. The measurements made at 633 nm wavelength are plotted in graphical form. However, some important results at 514 nm and 633 nm wavelengths are given in Table 1 and 2. 532 nm and 514 wavelengths fall in the green region of the spectrum and are useful in recording colour holograms if

if three primary colour (red, green and blue) radiations are simultaneously used for recording on the same plate.

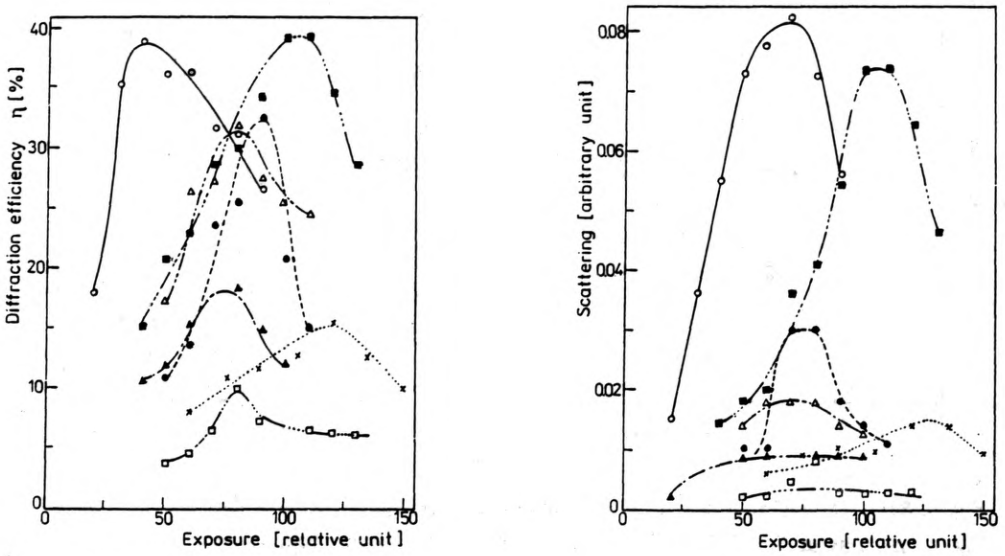

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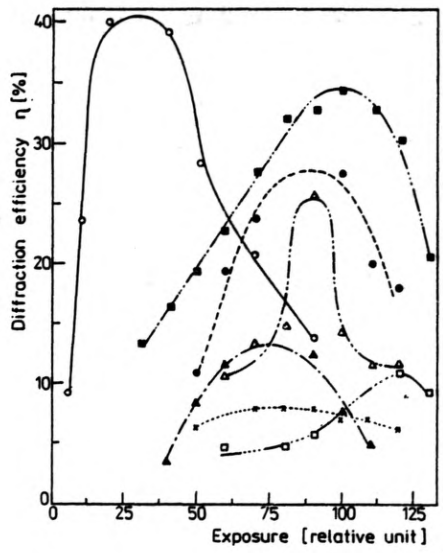
Fig. 1. Variation of diffraction efficiency as a function of exposure for the holograms produced in Kodak 649 F emulsion using potassium ferricyanide plus potassium bromide bleach with developers 1–7 (● — ● D19, o — o HRP, ▲–·–▲ IPC 163, △–···–△ IPC 76, ■–···–■ Ascorb acid, □–···–□ CW-C1, × ····· × CW-C2

Fig. 2. Variation of scattering as a function of exposure for the holograms produced in Kodak 649 F emulsion using potassium ferricyanide plus potassium bromide bleach with developers 1–7 (same as in Fig. 1)

Figures 1 and 2 show the variation of DE and scattering (arbitrary units) respectively as a function of exposure (relative units) for the holograms produced with potassium ferricyanide plus potassium bromide bleach process using developers 1–7. Similarly, Figures 3 and 4, 5 and 6, 7 and 8, and 9 and 10 show the variation DE and scattering respectively for the following bleaches: ferric nitrate and potassium bromide, ferric chloride plus concentrated sulphuric acid, potassium iodide and iodine and potassium dichromate plus potassium bromide. Figures 11 and 12 show the variation of DE and scattering for the holograms processed with Kodak D-19 developer and bleaches 1–3, and IPC 76 developer and bleaches 1–4.

The holograms developed in Kodak HRP and ascorbic acid developers show higher DE (Fig. 1). However, the scattering is also higher (Fig. 2), if potassium ferricyanide plus potassium bromide bleach is used. Holograms developed in Kodak D-19 and IPC 163 developers show medium DE. A good quality reconstruction has been obtained with Kodak D-19. IPC 163 and IPC 76 developers (Figs. 1 and 2). Here reconstruction quality is defined by the ratio I_d/I_s, where I_d is the diffracted intensity and I_s is the scattered intensity.



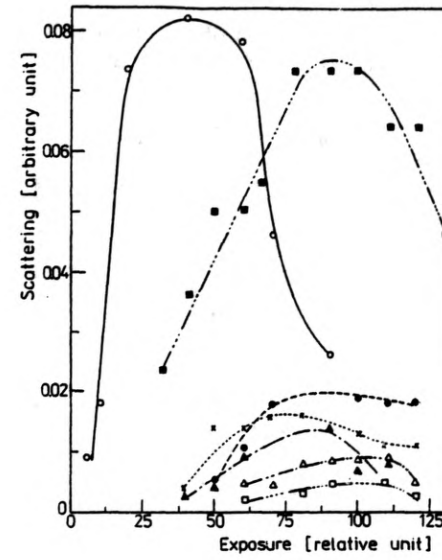
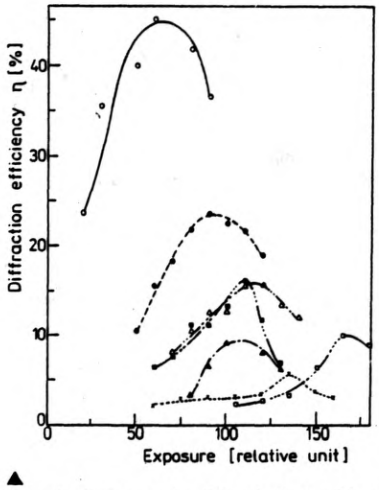


Fig. 3. Same as in Fig. 1, but with ferric nitrate plus potassium bromide bleach

Fig. 4. Same as in Fig. 2, but with ferric nitrate plus potassium bromide bleach



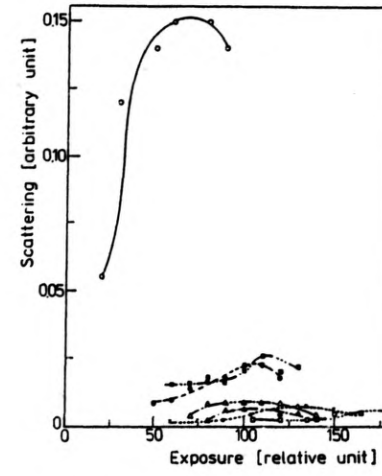


Fig. 5. Same as in Fig. 1, but with ferric chloride plus concentrated sulphuric acid bleach

Fig. 6. Same as in Fig. 2, but with ferric chloride plus concentrated sulphuric acid bleach

It is clear from Figures 3 and 4 that the maximum DE of the holograms has been obtained with Kodak HRP developer using ferric nitrate plus potassium bromide bleach. However, the best quality reconstruction has been achieved with ICP 76 developer and the ferric nitrate plus potassium bromide bleach process. The results shown in Figs. 5 and 6 have been produced with ferric chloride plus concentrated sulphuric acid bleach process and maximum DE has been achieved using Kodak

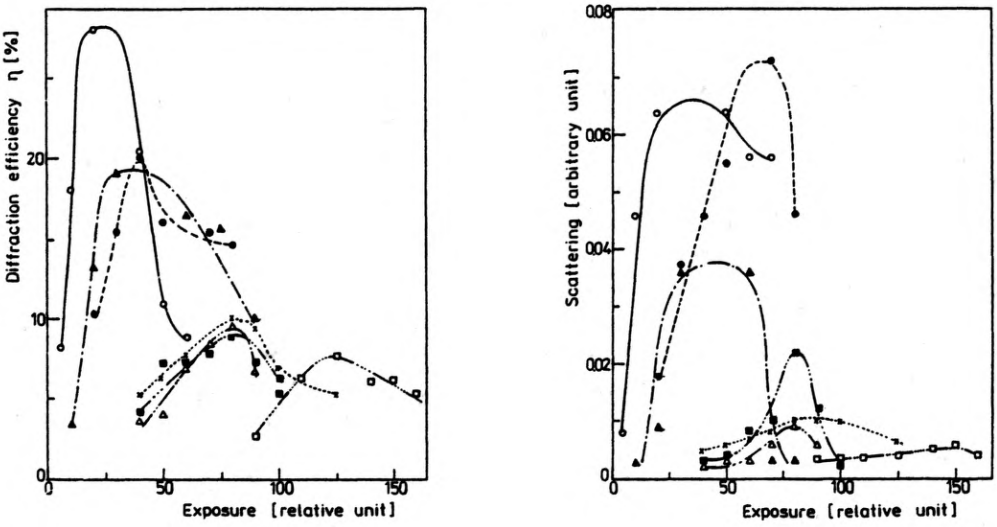


Fig. 7. Same as in Fig. 1, but with potassium iodide plus iodine bleach

Fig. 8. Same as in Fig. 2, but with potassium iodide plus iodine bleach

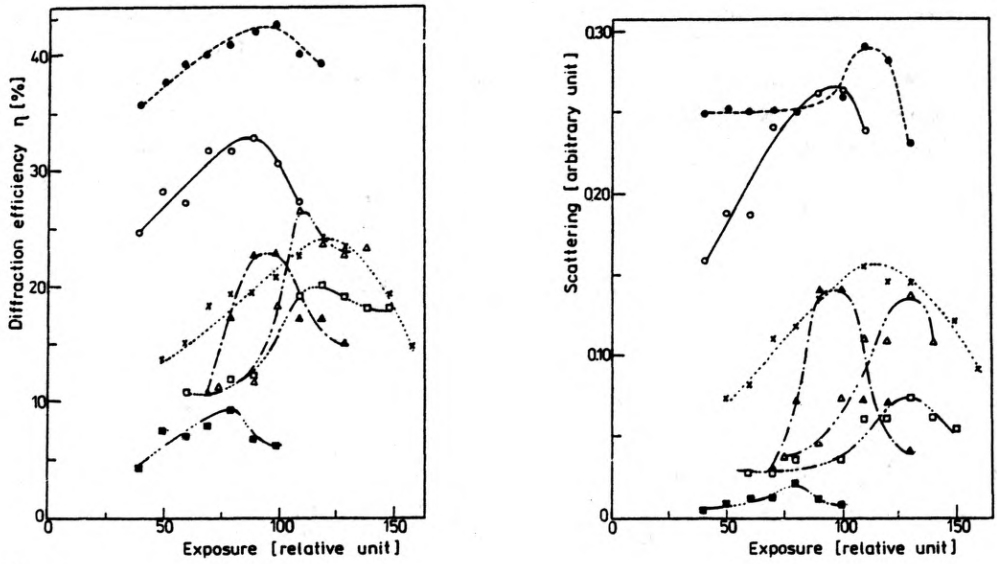


Fig. 9. Same as in Fig. 1, but with potassium dichromate plus potassium bromide bleach

Fig. 10. Same as in Fig. 2, but with potassium dichromate plus potassium bromide bleach

HRP developer. Results produced with different bleaches are somewhat similar to the results produced with potassium ferricyanide bleach plus potassium bromide bleach process. A good quality reconstruction has been achieved using IPC 76 and

and CW-C1 developer and ferric chloride plus concentrated sulphuric acid bleach process.

In the case of potassium iodide and iodine bleach process (Figs. 7 and 8) maximum DE has been obtained for the holograms developed in Kodak HRP developer. However, good quality reconstruction has been acheived using IPC 76, CW-C1 and CW-C2 developers. In the case of potassium dichromate plus potassium bromide bleach, though the best image quality has been achieved with CW-C1 developer, no developer produces holograms with good reconstruction quality using this bleach (Figs. 9 and 10).

The good quality reconstruction of the hologram has been achieved with the following pairs of developers and bleachers: Kodak D-19, IPC 163 and 76, CW-C1 and CW-C2 developers and potassium ferricyanide plus potassium bromide bleach process; Kodak D-19 and IPC 76 developers and ferric nitrate and potassium bromide bleach; Kodak D-19, IPC 163 and 76, CW-C1 and CW-C2 developers and ferric chloride plus concentrated sulphuric acid bleach; Kodak D-19, CW-C1 and CW-C2 developers and potassium iodide and iodine bleach. The remaining combinations have produced results of low reconstruction quality.

Seven combinations of developers and bleaches, which have produced better results are shown in Figs. 11 and 12 for comparison only. IPC 76 developer has produced good results with all the bleaches used. Potassium ferricyanide plus potassium bromide and ferric chloride plus concentrated sulphuric acid bleach processes show good results with Kodak D-19, IPC 76 and 163, CW-C1 and CW-C2 developers. Some important results of maximum DE and corresponding scattering are shown in Tables 1 and 2.

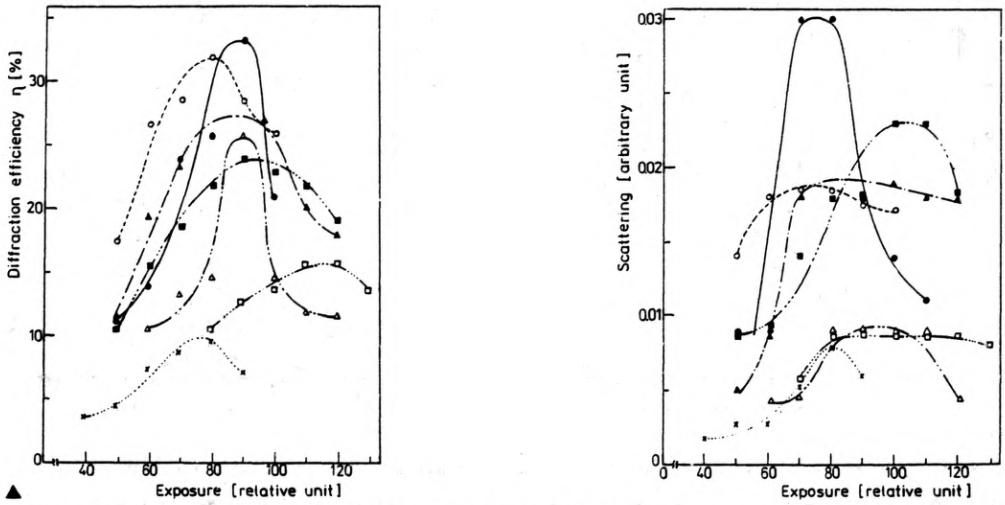


Fig. 11. Same as in Fig. 1, but with Kodak D-19 developer and bleachs 1–3 and IPC 76 developer and bleachs 1–4 (D-19: ●—● bleach 1, ▲—·—▲ bleach 2, ■—···—■ bleach 3; IPC 76: o-----o bleach 1, △—··—△ bleach 2, □—·—□ bleach 4, × ····· × bleach 4)

Fig. 12. Same as in Fig. 2, but with Kodak D-19 developer and bleachs 1–3 and IPC 76 developer and bleachs 1–4 (same as in Fig. 11)

T a b l e 1. Maximum diffraction efficiency and corresponding scattering using different developers and bleaches

Sample number	Developers	Bleaches	η_{max} (±0.5) at 633 nm	η_{max} (±0.5) at 514 nm	Scattering (±0.001) at 633 nm	Scattering (±0.001) at 514 nm
1	IPC 163	$K_3Fe(CN)_6$	18	16	0.100	0.016
2	IPC 163	$Fe(NO_3)_2$	12	12	0.010	0.010
3	D-19	$K_3Fe(CN)_6$	33	23	0.020	0.020
4	D-19	$Fe(NO_3)_2$	27	20	0.020	0.020
5	D-19	$FeCl_3$	23	19	0.020	0.010
6	D-19	KI+iodine	20	9	0.050	0.028
7	HRP	$K_3Fe(CN)_6$	39	25	0.060	0.020
8	HRP	$Fe(NO_3)_2$	40	25	0.080	0.050
9	HRP	$FeCl_3$	46	30	0.150	0.050
10	HRP	KI+iodine	20	15	0.070	0.020
11	IPC 76	$K_3Fe(CN)_6$	32	30	0.018	0.020
12	IPC 76	$FeCl_3$	16	15	0.010	0.015
13	Ascorb. acid	$K_3Fe(CN)_6$	39	30	0.073	0.045
14	Ascorb. acid	$Fe(NO_3)_2$	35	18	0.073	0.036
15	Ascorb. acid	$FeCl_3$	16	15	0.036	0.021
16	CW-C1	$Fe(NO_3)_2$	11	10	0.018	0.012
17	CW-C2	$K_3Fe(CN)_6$	16	12	0.014	0.010
18	CW-C2	$Fe(NO_3)_2$	8	8	0.016	0.013

T a b l e 2. Maximum diffraction efficiency and corresponding scattering using those combinations of developers and bleaches which produce results with low noise

Sample number	Developers	Bleaches	η_{max} (±0.5) at 633 nm	η_{max} (±0.5) at 514 nm	Scattering (±0.0005) at 633 nm	Scattering (±0.0005) at 514
1	IPC 163	$FeCl_3$	9	8	0.007	0.003
2	IPC 163	KI+iodine	19	12	0.040	0.005
3	IPC 76	$Fe(NO_3)_2$	26	24	0.009	0.010
4	IPC 76	KI+iodine	10	6	0.010	0.006
5	Ascorb. acid	KI+iodine	9	5	0.022	0.003
6	CW-C1	$K_3Fe(CN)_6$	10	6	0.009	0.003
7	CW-C1	$FeCl_3$	10	8	0.004	0.002
8	CW-C1	KI+iodine	8	6	0.004	0.006
9	CW-C2	$FeCl_3$	6	5	0.007	0.004
10	CW-C2	KI+iodine	10	7	0.009	0.003

Kodak HRP developer has produced maximum DE in most of the cases studied. However, the reconstruction quality was poor in each case. IPC 76 developer has produced good reconstruction quality with most of the bleaches with medium diffraction efficiency. Potassium ferricyanide plus potassium bromide and ferric chloride plus concentrated sulphuric acid bleach processes have produced good results with most of the developers. Ferric nitrate plus potassium bromide bleach process has produced holograms with good reconstruction quality using Kodak D-19 and IPC 76 developers.

We have also measured the diffraction efficiency of the bleached phase holograms recorded on Agfa-Gevaert 8E75 HD plates. Numerical values of some of the important results have been shown in Table 3.

Table 3. Maximum diffraction efficiency of the bleached phase holograms recorded on Agfa-Gevaert 8E75 HD plates using different developers and different bleaches

Sample number	Developers	Bleaches	η_{max} (±0.5) at 633 nm	η_{max} (±0.5) at 514 nm
1	D-19	$K_3Fe(CN)_6$	44.0	37.5
2	HRP	$K_3Fe(CN)_6$	45.0	36.0
3	CW-C2	$K_3Fe(CN)_6$	10.0	14.5
4	D-10	$FeCl_3$	27.5	32.0
5	HRP	$FeCl_3$	26.0	38.0

4. Conclusions

It may be concluded that maximum diffraction efficiency has been achieved using Kodak HRP developer and ferric chloride plus concentrated sulphuric acid bleach process. Minimum scattering has been produced with CW-C1 developer using ferric chloride plus concentrated sulphuric acid bleach process. CW-C1 developer shows lower scattering with all the bleaches used here.

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