PROCEEDINGS REPRINT

SPIE—The International Society for Optical Engineering

Reprinted from

Practical Holography VIII

7–9 February 1994
San Jose, California

Volume 2176

SOME REMARKS ON NOISE SOURCES IN SILVER HALIDE VOLUME HOLOGRAMS

A. Fimia, L. Carretero and A. Beléndez

Universidad de Alicante, Laboratorio de Optica
Departamento Interuniversitario de Optica
Apdo. 99, E-03080 Alicante. SPAIN

ABSTRACT

Dichromated gelatin has been established as the most frequently used recording material for the obtention of Holographic Optical Elements and new applications are being found for photopolymers in previously unexplored areas such as holographic interconnects. However, photographic emulsion from the beginning has been and continues to be the most used holographic recording material. This is due to the relatively high sensitivity and ease of processing of this material, improved processing chemistries, commercial films, and the repeatability of the results. In this paper we will analyze different sources of noise in photographic emulsions such as intermodulation noise, noise gratings and non-linear noise, and the influence of the photochemical process on the previously noise sources cited. Bleached emulsions by rehalogenating and solvent process will be considered and silver halide sensitized gelatin will be present as a solution in transmission holograms. At the same time, new developers and new noise models will be presented under the supposition that non-linear response of the recording material is due to the photochemical process.

1. INTRODUCTION

The first papers in the field of Holography dedicated to the analysis of noise sources focused on scattering in holographic gratings and on intermodulation noise in diffuse objects. These studies were based on the belief that there exists a linear relation between exposure and the index modulation obtained during the bleaching process.

At the same time, several different chemical compositions were developed to be used as bleaches in an attempt to suppress or minimize the sources of noise. Among these we find inversion processes or solvents¹ and rehalogenating processes² using tanning agents in the developer and bleaching baths³. In both cases, the goal was to obtain high diffraction efficiency and high signal noise. The first studies analyzed noise sources such as scattering, non-linearity and intermodulation noise in diffuse objects.

From a theoretical point of view, the study done by Upatnieks and Leonard⁴ offered the first theoretical model, and this model, together with the one presented by Kogelnik⁵ for holographic gratings, made it possible to analyze and study intermodulation noise in diffuse object holograms. It was assumed that the behavior of intermodulation noise was statistical in nature and that the variations in the average refraction index were proportionate to exposure. This model proved the importance that the beam ratio has in the signal to noise ratio of a diffuse object. More recent studies have shown that there exists noise sources which, due to the granular nature of emulsions, are called noise gratings⁶. These have been carefully studied both theoretically and experimentally over the last few years⁷. These noise gratings are one of the many sources of noise in the image of diffuse object holograms and they are influenced by the state of polarization of the reconstruction wave, the processing used and exposure⁸.

In this paper we will attempt to analyze the different sources of noise in diffuse objects using as a starting point the current knowledge that we have on photochemical processing with photographic emulsions.

2. REHALOGENATION WITH A FIXATION STEP

The first holograms of dielectric diffuse objects were obtained using processes in which the emulsion was developed, fixed and then bleached. These are known as rehalogenation processes and as part of the process, the exposed areas in which there are traces of metallic silver are subsequently processed, and as a result they once again have silver halide in them. This generates a clear difference in the refraction index of the silver halide gelatin area and the area where there is only gelatin.

In Figure 1 we show the diffraction efficiency and the SNR for three different developers, each of which is

Figure 1

Figure 2

characterized by a different slope of the D-logE curve. In all three, the same Potassium Ferricyanide and Potassium Bromide bleaching agent was used. Figure 2 shows the diffraction efficiency when the same developer is used with different beam ratios.

As is clearly seen, developers with only a slight slope (D-76) have a low diffraction efficiency and better SNR than those with a steep slope (D-8). Likewise, when the beam ratio (K) increases, SNR also increases, while at the same time diffraction efficiency decreases.

Because these processes present a very high noise level, Lamberts¹ proposed the use of solvent type bleaches. these produce a clear improvement in the SNR without causing a decrease in the diffraction efficiency. It is worth noting that in all cases, the SNR increases significantly for high exposures.

3. SOLVENT BLEACHES

These types of processing are characterized by the bleaching action taking place in the exposed area. They are not submitted to a fixing step and therefore the metallic silver grains dissolve and compensate the optic path between the exposed and unexposed areas due to the thickness variation that takes place. Figure 3 gives an example of the diffraction efficiency and signal noise for a typical solvent process. As can be seen, diffraction efficiency is lower than when rehalogenation with fixation is used, but the SNR is clearly higher.

4. REHALOGENATING BLEACHES WITHOUT FIXATION

The chemical processes involved in this type of bleaching process have been the cause of much controversy. Recently studies have been done which confirm the action of these bleaches⁹. In these processes, followed by developing, the emulsion is submitted to a rehalogenation process in which diffusion phenomena appear between the developed and undeveloped areas. This brings about a reordering of the material and consequently an index modulation between the exposed and unexposed areas. There is also occasionally a solvent action in these processes which produces small variations in thickness. Figure 4 shows the diffraction efficiency and the signal noise for this type of processing. As we can see, we obtain good diffraction efficiency and excellent signal noise. This is an improvement over the results obtained with solvent processing. Thus it is this type of processing that is most frequently used today.

5. THEORETICAL MODELS

All of the previous experimental results are difficult to prove with a theoretical model given the great number of parameters that come into play: exposure, developing and bleaching solutions, the type of processing, the linearity of the developer, slope, beam ratio, etc.

Upatnieks and Leonard were able to use their model to show that diffraction efficiency and SNR are a function of the beam ratio and at the same time point out the importance of the effects of volume when attempting to improve the SNR.

From the perspective of the coupled wave theory, and assuming that an object is a set of N waves, Kostuk¹⁰ attempts to create a model to show the relation between the SNR and the influence of the emulsion thickness. However, his results are also based on a linear relation between index modulation and exposure and they are not compatible with the results obtained by Upatnieks and Leonard. There was also the problem of the limitations of the numeric problem in the resolution of N coupled waves. We have recently presented the possibility of a non-linear relationship between exposure and the index modulation and have been able to prove high SNRs with very high exposures¹¹. Nevertheless, none of these models takes into account all of the noise sources that are found when a diffuse object is stored.

6. OPTIMIZATION PROCESSES IN BLEACHES

The first conclusion which we can draw from an analysis of the historic antecedents that we have is that all optimization processes should combine the correct selection of the developer with the correct selection of the bleaching solution. In Table I we show two possible developing and bleaching solutions that provide high energetic

Figure 3

Figure 4

(a)

(b)

Figure 5

sensitivity while at the same time achieving excellent signal to noise ratios and high diffraction efficiency. As can be seen, an ascorbic acid and phenidone developer was used along with a rehalogenating bleach without a fixation step. The concentration of bromide in this solution was adjusted in order to obtain a significant decrease in scattering. Figure 4 shows our results for diffraction efficiency and SNR when using R-10 and EDTA. SNR is clearly improved when using this last bleach and no loss of diffraction efficiency takes place.

Table I: Bleach formulas

	R-10	Fe	EDTA
Potassium bromide (K Br)	35 g	7 g	30 g
Potassium Ferricyanide ($K_3 Fe (CN)_6$)		8 g	
Potassium dichromate ($K_2 Cr_2 O_7$)	2 g		
Sulfuric acid ($H_2 SO_4$)	10 cc		10 cc
Ferric sulfate ($Fe_2 (SO_4)_3$)			30 g
EDTA disodium salt			30 g
Water to make	1 liter	1 liter	1 liter

Therefore, the first conclusion that can be drawn is that it is possible to increase the SNR without decreasing diffraction efficiency. However, we must first have a better understanding of the noise to signal ratios separately so that we can analyze the improvement obtained in the SNR.

In Figure 5 we show the angular response of (a) the noise and (b) the diffraction efficiency when the reconstruction angle is changed. As can be seen, we find that there is a low point exactly at the value corresponding to the Bragg angle, which is typical when noise gratings are present. An analysis of the transmitted zero-order leads us to the same conclusion (Figure 6). We find that if we compare the diffraction efficiency of the noise for rehalogenating processes with and without a fixation step, the noise level is lower in the latter case when the beam ratio is the same than it is when a fixation step is done in spite of the fact that in the rehalogenating process with fixation there are no noise gratings in the reconstruction direction due to thickness variations.

By analyzing reflection ratio, we see that there are also reflection noise gratings and they surely play a role in the fall in both diffraction efficiency and noise (Figure 7). Measurements taken after changing the state of polarization of the measurement beam show the disappearance of the low points mentioned previously which are typical of the noise gratings.

As far as we know, these effects have not been reported in the literature prior to this for cases in which noise gratings appear in diffuse object holograms. Additionally, as can be seen in Figure 7, the peaks corresponding to the decrease in diffraction efficiency also appear in the measurements of the noise ratio.

This second conclusion can be summed up by saying that in spite of the appearance of more noise gratings when rehalogenation processes with a fixation step are used than when these same processes without a fixation step are used, the levels of noise are lower for the processes without fixation.

The possible solvent action of the EDTA type rehalogenation bleaches and the use of developers without agents that give rise to oxidation products bring about the optimization and improvement of signal noise and diffraction efficiency.

7. SILVER HALIDE SENSITIZED GELATIN

In all of the processes analyzed above, the recording material has always been granular in nature. SHSGs have proven to be an alternative to bleaching processes and dichromated gelatins for transmission holographic gratings.

In a recent series of articles, some little-known models for the formation of latent images using this type of processing have been discussed. In Table II, an example of the processing used in our laboratory is presented.

The use of this hybrid processing for the storage of diffuse object holograms has produced the results presented in Figure 8. Although good levels of SNR are not achieved in the linear area of the developer, it is shown that it is

Figure 6

Figure 7

Figure 8

possible to obtain SNRs near 70 with diffraction efficiencies of 28% for diffuse objects when the beam ratio is $K = 5$. These results have not been achieved with any other material.

Table II: Processing schedule for SHSG

STEP
1.- Develop with PAAAC for 4 minutes.
2.- Rinse in running water for 1 minute.
3.- Bleach in a modified R-10 solution for 30 seconds after the plate has cleared at 50°C.
4.- Rinse in running water for 30 seconds.
5.- Soak in fixer F-24 for 2 minutes.
6.- Wash in running water for 10 minutes.
7.- Dehydrate in 50% isopropanol for 3 minutes.
8.- Dehydrate in 90% isopropanol for 3 minutes.
9.- Dehydrate in 100% isopropanol for 3 minutes at 50°C.
10.- Dry in vacuum chamber.

8. CONCLUSIONS

The progress that has been made in the analysis and optimization of bleaches has led to an improvement in image quality in diffuse object holograms. The relation between the SNR and diffraction efficiency cannot be justified with the current models we have. This optimization is fundamentally based on the correct selection of the concentrations and composition of the developing and bleaching agents in each step of the process.

The inclusion of noise gratings as a new source of noise in diffuse object holograms and the influence of these gratings on the final SNR present new perspectives for the analysis of noise in holography and at the same time allow

us to obtain more information about the behavior of photochemical processes involved in bleaching.

Rehalogenating processes without a fixation step produce the best SNR for a specific diffraction efficiency and a constant beam ratio. However, hybrid processes such as the ones used with silver halide sensitized gelatin and the "east-west" type process proposed by Phillips¹³, are undoubtedly the ones which in the near future, will produce excellent levels of SNR and diffraction efficiency.

And finally, we wish to mention that even though we have concentrated on the analysis of diffuse objects in this study, a large portion of the experimental results we have obtained are of great importance in the generation of interconnection holographic systems in which many object beams are also stored.

9. ACKNOWLEDGMENTS

Part of this work was supported by the *Direcció General d'Ensenyaments Universitaris i Investigació de la Generalitat Valenciana*, Spain (Project GV-1165/93).

A. Beléndez is also with the *Departamento de Ingeniería de Sistemas y Comunicaciones, Universidad de Alicante, Spain*.

10. REFERENCES

1. R. L. Lamberts, "Characterization of a bleached photographic material," *Appl. Opt.* **11**, 33-41 (1972).
2. R. L. van Renesse and F. A. J. Bouts, "Efficiency of bleaching agents for holography," *Optik* **38**, 156-168 (1973).
3. N. J. Phillips, A. A. Ward, R. Cullen, and D. Porter, "Advances in holographic bleaches," *Photogr. Sci. Eng.* **24**, 120-124 (1980).
4. J. Upatnieks and C. Leonard, "Efficiency and Image contrast of dielectric holograms," *J. Opt. Soc. Am.* **60**, 297-305 (1970).
5. H. Kogelnik, "Coupled wave theory for thick hologram gratings," *Bell Syst. Tech. J.* **48**, 2909-2947 (1969).
6. R. R. A. Syms and L. Solymar, "Noise gratings in photographic emulsions," *Opt. Commun.* **43**, 107-110 (1982).
7. L. Carretero, A. Beléndez and A. Fimia, "Holographic noise gratings for analysing and optimizing photochemical processings in bleached silver halide emulsions," *J. Mod. Opt.* **40**, 687-697 (1993).
8. A. Beléndez, L. Carretero and I. Pascual, "Polarization influences on the efficiency of noise gratings recorded in silver halide emulsions," *Appl. Opt.* (in press).
9. P. Hariharan, "Basic processes involved in the production of bleached holograms," *J. Photogr. sci.* **38**, 76-81 (1990).
10. R. K. Kostuk, "Comparison of models for multiplexed holograms," *Appl. Opt.* **28**, 771-777 (1989).
11. A. Fimia, A. Beléndez and L. Carretero, "Signal to noise ratio of non-linearly recorded holograms of diffuse objects," *Phys. Lett. A* (submitted).
12. A. Fimia, A. Beléndez and I. Pascual, "Silver halide (sensitized) gelatin in Agfa-Gevaert plates: the optimized procedure," *J. Mod. Opt.* **38**, 2043-2051 (1991).
13. N. J. Phillips, "Bridging the gap between Soviet and western holography," *SPIE Institute Series*, Vol. IS8, 206-214 (1990).