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SILVER-HALIDE SENSITIZED HOLOGRAMS AND THEIR APPLICATIONS

A. Fimia, I. Pascual, C. Vázquez and A. Beléndez

Dpto. Interuniversitario de Optica. Univ. Alicante. Apdo. 99, Alicante 03080. Spain.

ABSTRACT

Silver-halide sensitized gelatin has the sensitometric and spectral response of silver halide emulsions and the holographic characteristics of dichromated gelatin, and therefore when properly processed it has little scattering and absorption. Silver-halide sensitized gelatin is one of the most promising techniques today for the fabrication of transmission holographic optical elements. In this paper we will first review the mechanism of hologram formation in silver halide sensitized holograms. The most important steps of processing -the influences of the developer on the modulation transfer function and of bleaching on the difraction efficiency- will be analized.

Holographic characteristics such as exposure sensitivity, resolution, thickness change and evironmental stability will be pointed out.

Through optimized processing we have been able to fabricate holographic optical elements, including a holographic scanner and different off axis holographic lenses. These will be analyzed from the point of view of the recording material.

1. INTRODUCTION

Silver-halide sensitized gelatin is a processing technique which combines the energetic and spectral sensitivity of photographic emulsions with the high diffraction efficiency and the low level noise of dichromated gelatins.

The technique was initially developed by Pennington, Harper and Laming,[1] though the technique in its present day state is due to the work of Graver, Gladden and Estes[2] on one hand and to that of Chang and Winick[3] on the other.

One of the problems involved in this processing technique lies in the fact that the resolution power obtainable is dependent on that of the photographic emulsion. Ferrante[4] has studied this aspect closely and has found a significant decrease when we get to 2000 l/mm. Hariharan,[5] has analyzed the influence of the developing and bleaching bath on the photochemical process, whereas Angell[6] has recently optimized the processing for the Kodak 649F emulsion.

In this paper we are going to show the results we have obtained using Agfa-Gevaert plates. These results are based on a modification of Chang and Winick's processing technique and on Chang's[7,8] results with dichromated gelatin.

2. PHOTOCHEMICAL PROCESSING

Once the photographic emulsion has been exposed, it is developed and then bleached. Due to the action of the bleacher the developed silver is oxidized to Ag^{+}, whereas the Cr^{+6} ion is reduced to Cr^{+3} during the same bleaching wash. In this way the Cr^{+3} ion is linked to the gelatin chains in the vecinity of the oxidized silver grains thereby achieving a variation in the degree of hardening between the exposed and non-exposed zones of the emulsion.

The emulsion is then fixed to remove all the excess silver halides. The processing is completed with the washing of the emulsion and its dehydration through successive baths in isopropanol, similar to the processing of a dichromated gelatin.

With this classic processing we obtained a maximum efficiency $\sim$45% lower than the 80% efficiency obtained using Kodak 649F plates. This problem was apparently caused by the extremely high degree of hardening of Agfa gelatin which reduces its modulation capability. The same problem which arises when DCG holograms are derived from Agfa plates has been solved by soaking the plates in a hot water bath before exposing.[9]

According to this we have studied and optimized the process in its different steps.

All the stages in the processing of 8E75HD and 8E56HD plates are shown in detail in Table I.

Diffraction gratings between 400 and 2000 l/mm were recorded using two 633 nm He-Ne laser

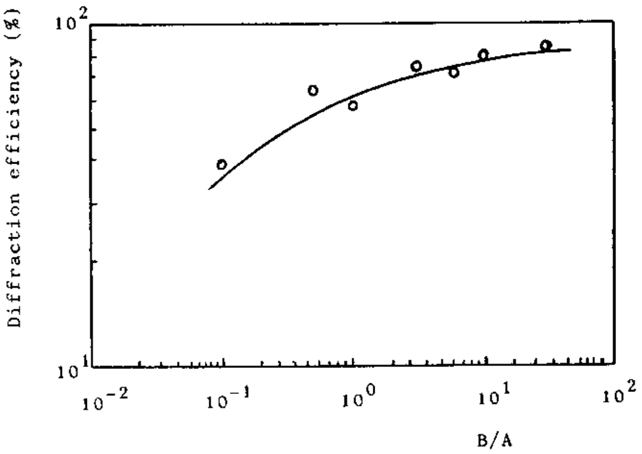

Figure 2

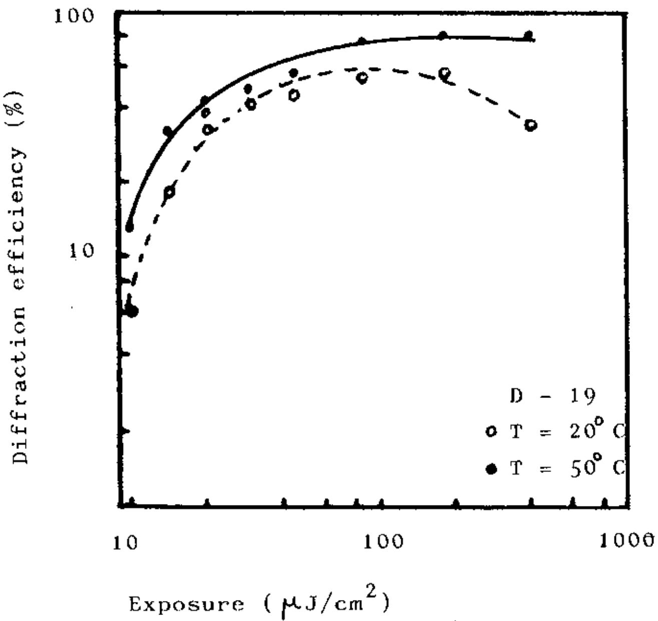

Figure 3

3. HOLOGRAPHIC CHARACTERISTICS

There are four holographic characteristics that we have analyzed: exposure requirements, noise, modulation transfer function and environmental stability.

The exposure requirements of SHSG holograms are relatively low for maximum efficiency, about 80 $\mu J/cm^2$ for D-19 and 200 $\mu J/cm^2$ for PAAP. More over this exposure can be lowered even more with hypersensitization techniques. Thus, the light sensitivity of SHSG holograms is $\sim 10^3$ times that of DCG holograms.

Two noise sources can be distinguished: (a) the setup; and (b) the processing. The setup noise appears when some element such as a lens or a mirror is placed between the pinhole and the plate. The light passing through the element is partly scattered and consequently a random-phase pattern is recorded on the plate. Processing noise appears when the degree of hardening of the gelatin is too low, when the temperature of some of the baths is too high and when the type of developer used changes. Fortunately, both these noises can be eliminated in SHSG holograms of diffuse-objects.[10]

Figure 4 shows the noise a function of exposure for two grating-forming systems: a) spatially filtered divergent beams, and b) plane beams by using collimating lenses. To show the influences of the temperature of the bleaching bath we include the results obtained at 20°C and at 50°C in figure 5.

In figure 6 we have represented the influences of developing on noise levels, and as we can see, for exposures up to 100 $\mu J/cm^2$ the noise level is less than 1%. Noise was measured using the equation:

$$\text{Noise} = \frac{I_t - I_d}{I_i} \times 100 \qquad (1)$$

where I_t is the total transmitted light in the diffraction direction, I_d the difracted light and I_i the incident light. It can be seen that noise decreases quickly, becoming negligible for exposures where efficiency is kept at the maximum value.

The major disadvantage of SHSG holograms when compared to DCG holograms is that their response at high spatial frecuencies is limited. Figure 1 shows diffraction efficiency as a function of spatial frecuency for two developers. It is seen that maximum efficiency is only obtained in the range between 600 l/mm an 1000 l/mm for D-19 whereas with PAAP this level of efficienciescan obtained up to 1600 l/mm. At higher frecuences, efficiency is limited because of the granular distribution of silver halide crystals in the emulsion.

The eventual diffusion of trivalent chromium ions towards the unexposed regions will decrease efficiency, especially at higher frecuencies. At lower frecuencies, efficiency decreases because an important fraction of light intensity is difracted to form the conjugate first-order image and higher-order images. At a mean frecuency of 800 l/mm, we were able to make maximum efficiency and low noise holographic elements with D-19 as the developer.

The environmental stability of SHSG holograms is similar to that of DCG holograms. We found that SHSG holograms are stable under ordinary room atmospheric conditions, but when the relative humidity is very high, (∿90%) they degrade in a few hours. However, they can be retrieved by repeating the final isopropanol dehydration bath. Good environmental stability is only obtained by means of a glass cover cemented to the gelatin surface, a common practice in DCG holography.[12] In figure 7 we have represented the variations of diffraction efficiency as a function of the energy received by the plate.

4. APPLICATIONS OF SILVER HALIDE SENSITIZED GELATIN

Characteristic properties of SHSG which result from the use of the current processing are summarized in Table II. The immediate application of SHSG appears to be transmision holographic lenses and laser scanners.

4.1. Holographic lenses

Some of the advantages offered by holographic optical elements include their easy production, their reduced weight and volume & their ability to store information in layers just a few microns thick. Taking this into account, it is possible to make optical elements of considerable size. In figure 8, we have represented the map of diffraction efficiencies of a holographic collimate as a function of pupil coordinates. The mean frecuency is 800 l/mm and the noise level is less than 3%. As can be seen, the distribution of efficiencies is quite uniform.

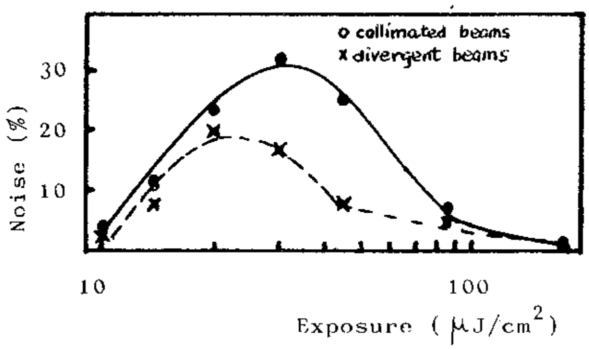

Figure 4

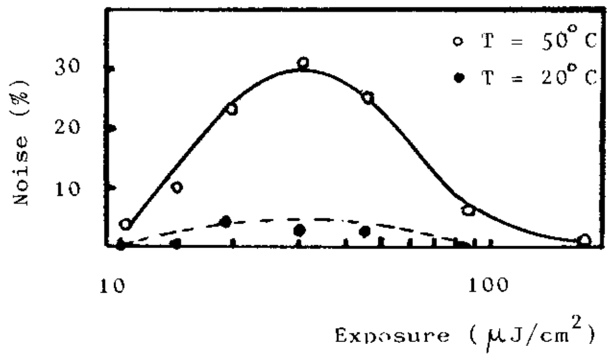

Figure 5

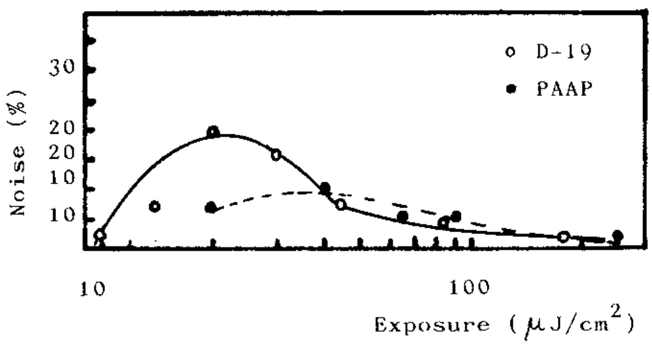

Figure 6

4.2. Laser scanners

The use of holographic scanners is on the increase. We have designed a scanning system that allows us to scan an area measuring 5 x 5 cm at a distance of 50 cm. The system consists of 35 gratings with a spacial frecuency of 1170 - 1290 l/mm which permits the scanning of the desired area.

5. CONCLUSIONS

We have described the processing technique for silver halide sensitized gelatin in Agfa-Gevaert emulsion taking into account the different types of gelatin with respect to Kodak 649F plates, and we have also optimized this processing and analyzed the holographic characteristics such as the modulation transfer function, the noise, the diffraction efficiency or the energetic sensitivity.

With the method proposed above, we have achieved an optimization of the processing technique which enables us to obtain a diffraction efficiency response of more than 60% between frecuencies of 600-2000 l/mm and a noise level inferior to 1%.

Also, we have made holographic lenses and scanners to confirm the possibilities of the process in the design production of transmission holographic optical elements.

Table II. Characteristics Summary of SHSG

Spectral sensitivity	Panchromatic	8E75 HD 8E56 HD
Exposure sensitivity	D-19 PAAP	0.08-0.1 mj/cm^2 0.2-0.4 mj/cm^2
Resolution	D-19 PAAP	600-1000 lines/mm 400-1600 lines/mm
Noise	D-19 PAAP	less than 3% at high density before bleaching

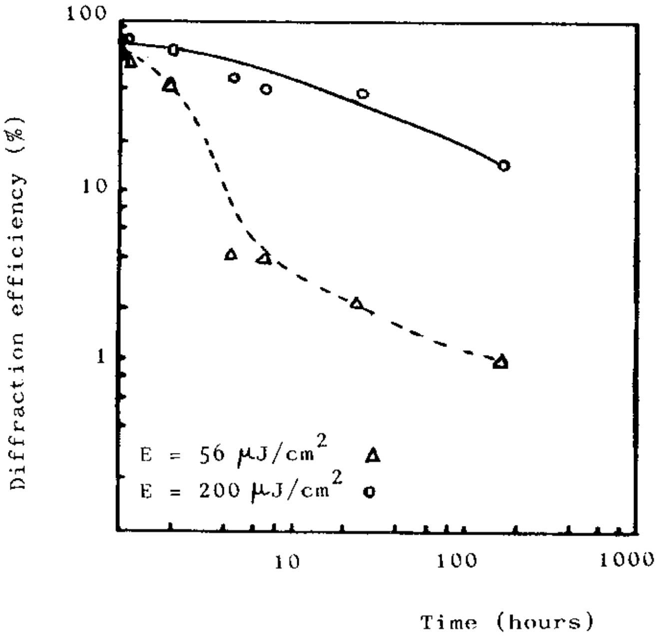

Figure 7

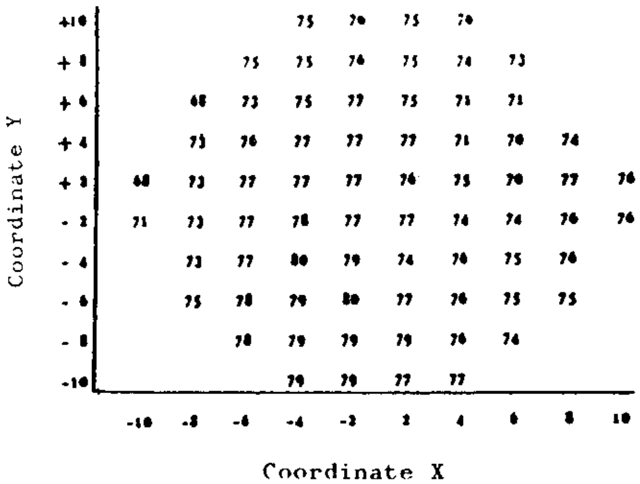

Figure 8

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beams of equal intensity in a convential holographic device of symmetrical geometry.

Table 1. Processing schedule for silver-halide sensitized gelatin holograms (8E75HD plates) (all solutions at 20° C)

Step
1. Develop with Kodak developer D-19 for 5 minutes. (PAAP for 4 min).
2. Rinse in running water for 1 minute.
3. Bleach in a modified R-10 solution for 30 seconds after the plate has cleared (for formula see below).
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 per cent isopropanol for 3 minutes.
8. Dehydrate in 90 per cent isopropanol for 3 minutes.
9. Dehydrate in 100 per cent isopropanol for 3 minutes.
10. Dry in vacuum chamber.

Bleach formula

Solution A	
Distilled water	500 ml
Ammonium dichromate	20 g
Concentrated sulphuric acid	14 ml
Distilled water to make	1000 ml
Solution B	
Potassium bromide	92 g
Distilled water to make	1000 ml

Just before use, mix one part A with ten parts distilled water, then add thirty parts B.

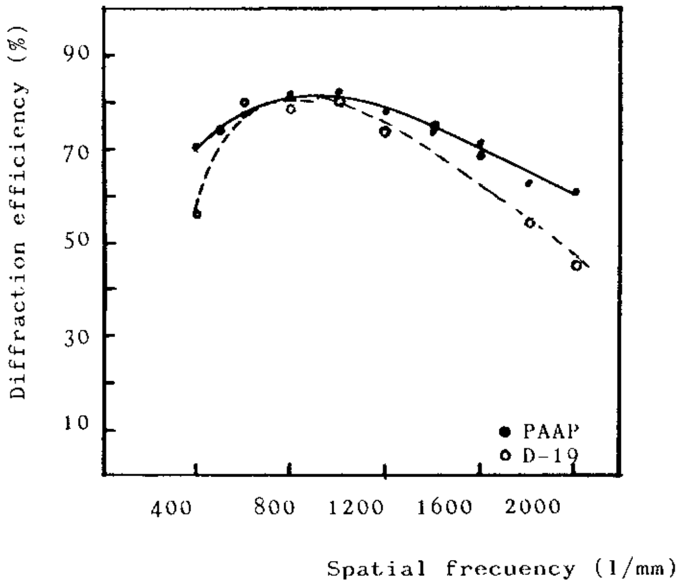

Figure 1

2.1. The influence of the Developer

As is already known[5] due to its composition, the developer has an influence on the final diffraction efficiency as well as on the value of the modulation transfer function. We think that this is due to the fact that the oxidation productions coming from the hydroquinone, which favour in low frequencies the obtaining of the final differential hardening, turn out to have a negative action for high resolution values. The non-solvent developer PAAP[9] produces better resolution than the developer D-19 as can be seen in figure 1.

2.2. The influence of Bleaching Process

There are two steps in the bleaching process that most influence outcome. The first one is the concentration ratio between baths A and B of the bleaching process. As we can see in figure 2, when we increase the ratio B/A there is an increase in diffraction efficiency. This is because by adjusting the ratio of stock solution B to stock solution A, it is possible to control the life span of the chromium ion Cr^{+3}. According to B.J. Chang[3] as the amount of solution B increases[5], the life span of the chromium ion decreases and the crosslink bonds occur near the metalic silver.

The second step to be considered is the increase in temperature of the bleaching bath. As we can see in figure 3, this brings about an increase in diffraction efficiency, which is a direct consequence of the higher variation of the average hardening of the gelatin. We see that efficiencies as high as 80% can be obtained at a bleaching temperature of 50°C. In this case, the light intensity indicates that the diffracted intensity is almost the maximum obtainable in SHSG.

The rest of the process was not modified except in the Fix steps in which we used F-24 non-hardening bath. The process of water and isopropanol baths is typical of DCG.