SILVER HALIDE SENSITIZED GELATIN AS HOLOGRAPHIC RECORDING MATERIAL

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ABSTRACT

Silver halide sensitized gelatin (SHSG) has proven to be a good alternative to dichromated gelatin and bleached emulsions in the production of volume phase holographic optical elements. In the present paper, the processing procedure for SHSG derived from Agfa-Gevaert holographic plates is reviewed and the holographic characteristics of the processed SHSG are experimentally measured and analyzed. Several important aspects related to the influence of the developer and the bleach bath, the noise, the diffraction efficiency, the modulation transfer function and the optimized procedure have been considered. Both transmission and reflection holographic gratings and diffuse-object holograms are described in detail.

KEY WORDS: Holography; photosensitive materials; photosensitive processing; holographic optical elements

1.- INTRODUCTION

Holographically formed optical elements have shown potential as an attractive alternative and a viable supplement to conventional refractive and reflective optics¹. The attributes of holographic optical elements (HOE's) include their low weight, compact size, large apertures, multiplex possibilities and the ease with which they can be mass-produced through replication. High diffraction efficiency may be achieved, particularly when generating HOE's as volume phase holograms because these holograms can produce efficiencies nearly of 100%². It is well known that several critical factors hinder the performance of a volume HOE. Some of these are related to the holographic recording material used for making the HOE. In order to analyze the recording material it is necessary to consider several holographic parameters including diffraction efficiency, angular and spectral selectivities, environmental stability, refractive index and thickness changes, shear-type effects and the signal-to-noise ratio.

The obtention and optimization of new recording materials in Holography is fundamental to the advancement of the field. Even though computer generated holograms have revolutionized the theoretical foundations of Holography, it is the obtention of new recording materials that will make it possible to move from theory to experimentation to industrial applications.

Several materials are available for holographic storage, such as silver halide emulsion, dichromated gelatin, photopolymers, ferroelectric crystals, photochromic and photodichroic materials, fiber photorefractive materials, and so on³⁻⁵.

Dichromated gelatin has been established as the most frequently used recording material for the obtention of HOE's⁶ and new applications are being found for photopolymers in previously unexplored areas such as holographic interconnects⁷ or holographic memories⁸. But from the outset, photographic emulsion⁹⁻²³ has been and continues to be the most frequently used holographic material. This is due to its photochemical characteristics: it is a panchromatic material with high sensitivity. Add to this the fact that the knowledge of photochemical processes has advanced greatly, and we find that this is an ideal material for the experimental testing of holographic concepts, theoretical models such as Kogelnik's² or the EHGM²⁴⁻²⁵, for example, or for the analysis of many noise sources that are present in Holography.

A photographic emulsion consists of fine grain silver halide crystals suspended in a gelatin base which provides cohesion. Therefore it is basically a granular medium which is quite an important factor in its spatial resolution- which itself is an important aspect of holographic materials- but it is also an important source of noise. The gelatin in which the grains are suspended is important in some processes which we will discuss later in this paper. The most important parameter in its definition is the swelling factor which can be defined as:

$$S_w = \frac{W - W_0}{W_0} \quad (\%) \quad (1)$$

where W_0 is the weight of the dry gelatin layer and W the weight of the gelatin layer after submersion in 18°C water for 15 minutes. This swelling factor is important in some bleaching processes and fundamental in the use of layers of gelatin.

Among the most frequently used emulsions we find Ilford, 649F by Kodak, and Agfa-Gevaert emulsions. In this review we will deal mostly with Agfa-Gevaert 8E75 HD emulsion.

Silver halide sensitized gelatin (SHSG) has proven to be a good alternative to dichromated gelatin and bleached emulsions in the production of HOE's. Their high energy sensitivity together with their chromatic sensitivity (based on the spectral response of the photographic emulsion which forms the base of the process) make it possible to obtain HOE's in any part of the visible spectrum. SHSG 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. This technique was initially developed by Pennington, Harper and Laming²⁶, though the technique in its present day state is the result of the work done by Graver, Gladden and Eastes²⁷ on the one hand and Chang and Winick²⁸ on the other.

One of the problems involved in this processing technique lies in the fact that the resolution power is dependent on the power of the photographic emulsion. Ferrante²⁹ has studied this aspect closely and has found a significant decrease when we get to 2000 lines/mm. Hariharan³⁰, in turn, has analyzed the influences of the developing process, whereas Angell³¹ has optimized the processing for Kodak 649F emulsion. More recently, many papers have analyzed the optimization of this processing technique and how it can be used to make HOE's³²⁻³⁷. Recently, the processing formula presented in this paper was modified to achieve high diffraction efficiency and an acceptable modulation transfer function within the region of spatial frequencies of interest in making holo-couplers as fan-out devices³⁸.

In this review we show most of the experimental results that we have obtained in our Laboratory during the last years for the Agfa 8E75 HD emulsion, these being based on the modification in Chang and Winick's processing for this technique and on Chang's results with dichromated gelatin³⁹.

2.- PHOTOCHEMICAL PROCESSING

Experiments were carried out with Agfa-Gevaert 8E75 HD emulsion. Unslanted holographic transmission gratings with spatial frequencies between 1000 lines/mm and 2000 lines/mm were recorded by using two collimated beams of equal intensity from an He-Ne laser. Figure 1 shows in detail all the steps in the processing of Agfa 8E75 HD plates, and all the stages in the processing are shown in Table I.

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 bath. This way the Cr^{+3} ion is linked to the gelatin chains in the vicinity of the oxidized silver grains achieving a variation of hardening between the exposed and nonexposed 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 iso-propanol, following a process similar to that of a dichromated gelatin (Figure 2 and Table II).

With this classic processing we achieve 50% diffraction efficiency for gratings with the 8E75 HD emulsion (and a 60% with Kodak 649F, Figure 3),

worse results than those obtained by Angell³¹. From our point of view, this drop is due to the fact that the degree of hardening found when using Agfa emulsion gelatin is not the right one, if we compare it to that of the 649F emulsion.

Taking into account that the link between the processing of a photographic emulsion and that of a dichromated gelatin is the wash in water (Table II, step 11), we think it is at this point that we can establish a control for the analysis of the processing and its subsequent optimization. Thus, from this stage, we have measured the diffraction efficiency and used our results to study the aspects which have an influence on the formation of a latent image during this processing: the developer and the bleaching. We shall study them separately in the following sections, and identify the possibility of optimization which we have referred to.

3.- THE INFLUENCE OF THE DEVELOPER

As is already known¹⁸, the developer, due to its composition, influences the final diffraction efficiency and the value of the modulation transfer function. As can be seen in Figure 4, the results of the measurement of diffraction efficiency during the wash in water for developers of the D-19 type are better than the ones we get for developers of the PAAP type for different spatial frequencies. Nevertheless, final efficiency during drying is higher at 2000 lines/mm for PAAP than for the D-19. This is due to the fact that the oxidation products coming from the hydroquinone, which favour low the obtention of the final differential hardening at low frequencies, turn out to have a negative action for high resolution values. It is possible then to

improve the results obtained for high frequencies by working during the processing with developers which don't give rise to oxidation products.

4.- THE INFLUENCE OF THE BLEACHING PROCESS

At this stage of the processing we can choose between two possible methods. On the one hand it is possible to modify the degree of hardening of the gelatin and on the other hand, we can modify the composition of the bleach bath. In Figure 5 we show diffraction efficiency measured in the water wash and after the final drying. In both cases, we show the results for two different temperatures of the bleacher. As can be seen, the increase in temperature brings about an increase in diffraction efficiency, which is a direct consequence of the higher variation of the average hardening of the gelatin as the temperature rises.

The use of washes in water before and after the bleaching process at a temperature of 50°C leads to an increase in diffraction efficiency during the final stage. There is no increase in efficiency, however, in the intermediate stage of the wash in water, which prevents us from reaching the highest possible efficiency in these cases, as we can see in Figure 6. The second effect of the bleaching depends on the concentrations of bromide and dichromate ions that are used, so that the higher the ratio between Br^- ions with respect to Cr^{+6} ions, the higher the diffraction efficiency measured after the final drying (Figure 7).

5.- PROCESSING OPTIMIZATION

According to what we have seen, the PAAP developer, due to its low content of oxidation products, achieves high diffraction efficiencies, as well as excellent values as regards the modulation transfer curve. On the other hand, and since the latent hardening image is produced during the wash in the bleacher and considering that during this same stage we can control the average degree of hardening of the gelatin, we can infer that we can possibly optimize the different stages of the photochemical processing in such a way as to make possible the obtention of high diffraction efficiencies within a wide range of frequencies.

In the tests that we have carried out we have proven that a 24-hour break after the bleaching during which we keep the plate at a relative humidity of more than 80%, produces an improvement in the results obtained. In Figure 8 we show the diffraction efficiency taken both in the water wash and after the drying, when using the PAAP developer and then, going on to the stage of bleaching in the way we have shown. To this we have added a break between the bleaching and water baths. As can be seen, the result shows that we can work between 1000 and 2000 lines/mm, with a modulation transfer function with efficiency values of more than 70%. We think the optimization as a whole can be the result of a short of reaction such as the "darkness reaction", as happens when dichromated gelatin is used for the sensitizing of gelatin layers (Figure 2).

It is possible to obtain and to control the hardening bias level in SHSG by analyzing either the developer-oxidizing products or the tanning action of the bleach bath³⁶. In order to optimize the process it is necessary to take into

account the relationship between the diffraction efficiency measurements in the water tank (before dehydration) and those taken after the final alcohol developing, according to the method proposed by Chang and Leonard⁶ for dichromated gelatin.

In Figure 9 we present the experimental measurements of noise in diffraction gratings for different beams (collimated and divergent), different temperatures of the bleaching bath and for different developers. The noise is measured according to the equation:

$$\text{Noise} = \frac{I_d - I_t}{I_i} \quad (2)$$

where I_t is the total transmitted light in the diffraction direction, I_d the diffracted light and I_i the incident light. In Figure 10 we present the geometric disposition of the measurements schematically. It can be seen that noise decreases quickly, becoming negligible for exposures when efficiency is kept at the maximum value. In Figures 11 and 12 we have represented the influences of the developer and the temperature of the bleaching bath on the noise, respectively. In a recent paper the processing formula was modified without elaborating on the technique³⁸. These researches have solved the problem of a high degree of initial hardening by soaking the plates after the fixing step in hot water, $T = 75^\circ\text{C}$ for 10 minutes. In Table III we point out the processing schedule. According to these authors the latent image formation is due to the combination of gelatin and isopropanol³⁸. On the other hand, it has also been proposed recently that the formation mechanism of a microvoids structure in silver halide reflection holograms is the latent image formation principle⁴⁰.

6.- DIFFUSE-OBJECT HOLOGRAMS

While it is true that diffraction efficiency is fundamental from the perspective of HOE's, it is also true that the signal-noise ratio is basic when dealing with diffuse-object holograms. From the different sources of noise in phase diffuse-object holograms recorded in SHSG, noise gratings do not exist due to the fact that this processing technique introduces considerable emulsion thickness changes. Due to this, the principal sources of noise that we must consider are scattering and the intermodulation noise caused by the self-interference of light from the extended object.

For a long time, studies have been done on these last noise sources in our Laboratory. The object used was a 2x2 cm square with a concentric 1x1 cm square (Figure 13). It was placed 30 cm; from the plate and the reference beam formed a 40° angle with the normal of the plate (Figure 14). Once the plate was processed, the real image was reconstructed by measuring the intensity levels of both sides of the square and the central region. The following equation was used as signal-noise ratio:

$$SNR = \frac{I_1 + I_2}{2 I_0} \quad (3)$$

The results are summarized in Figure 15. Transparency, SNR and efficiency are plotted as functions of the density before bleaching. We include in the graph, readout measurements made at 488 nm (solid lines) and 633 nm (broken lines). It can be seen that the transparency remains high, and the SNR increases considerably for high densities before bleaching. These results are excellent if we think of this processing technique as useful for the manufacture of masters.

In a recent research study⁴¹ done with diffuse-object holograms we found that current theoretical models on the formation of latent images cannot completely account for the storage of information in SHSG holograms. These results justify the need to modify existing models in order to be able to justify all of the experimental results obtained with this type of processing.

7.- REFLECTION HOLOGRAPHIC GRATINGS

SHSG has the same spatial frequency response as the photographic emulsion used at the outset and this makes it difficult to obtain high diffraction efficiency when the spatial frequency is more than 4000 lines/mm, that is, when we want to obtain reflective HOE's³⁵.

Reflective diffraction gratings were recorded with two collimated beams of equal intensity illuminating the plates from opposite sides. The angle between the two beams was 150° in air, and the incidence of one of the beams on the plate was normal. The illumination source was an He-He laser and sets of gratings with the exposure varied were processed according to Table III with only slight variations in the concentrations of potassium bromide and potassium dichromate in the bleach. Each grating was analyzed in an Oriel 7240 monochromator that maintained the recording geometry and varied the replay wavelength to obtain minimum light intensity in the transmitted beam. In Figure 16 we have represented the experimental results obtained.

Figure 17 shows the maximum diffraction efficiency and the wavelength when the concentration of dichromate is changed and the concentration of bromide remains constant. Figure 18 shows the maximum

diffraction efficiency and the wavelength when the concentration of bromide is changed while the dichromate level stays the same. We can see that a change in dichromate for a high concentration of bromide does not affect the maximum diffraction efficiency. However, a change in bromide controls the average life span of the dichromated ions, producing only a local effect, and as a result, high index modulations can be achieved. As can be seen, the dichromate is the cause of the variations in the differential hardening. This allows the reconstruction wavelength to vary by more than 50 nm, by appropriately selecting the concentration level of dichromate. Bromide, as we see, also causes small variations in thickness; however, this variation is less than what was cited previously.

Through experimentation it has been shown that it is possible to obtain variations between 50 and 70 nm, in the reconstruction wavelength by controlling the concentration of bromide and dichromate in the bleaching bath. Nevertheless, it has not been possible to obtain a diffraction efficiency of more than 55% in these tests. Bandwidths of 25 nm were obtained as can be seen in Figure 19. The energy necessary to do so was $400 \mu\text{J}/\text{cm}^2$, about 100 times higher sensitivity than dichromated gelatin.

8.- APPLICATIONS

One of the most important area of application of SHSG has been the manufacture of original HOE's for copying processes and mass production. As an example, holographic lenses and diffraction gratings have been obtained with these techniques⁴²⁻⁴³.

On the other hand, lenses for different holographic imaging

systems⁴⁴⁻⁴⁵, high efficiency holographic collimators⁴⁶ and holographic scanners³³ have been obtained because of high sensitivity of SHSG, and fanin-fanout devices with equal grating strength and acceptable intensity ratio between the output beams have been made⁴⁷.

Due to the excellent diffraction efficiency and SNR achieved with this photochemical process, it is possible to obtain an excellent material for volume recording of information and holographic interconnect applications^{38,45}.

9.- CONCLUSIONS

In the present paper, the processing procedure for SHSG derived from Agfa-Gevaert plates is described in detail. This processing has been optimized and the holographic characteristics, such as the modulation transfer function, the noise, the diffraction efficiency and the energetic sensitivity has been analyzed. With our optimized processing we have achieved a diffraction efficiency response of more than 60% for transmission gratings with frequencies between 600 and 2000 lines/mm. We have shown that it is possible to make reflection holograms with diffraction efficiencies higher than 50% by letting the reconstruction wavelength differ by between 50 and 70 nm from the recording wavelength. Finally, we have carried out experiments on both diffraction efficiency and SNR for diffuse-object holograms. Nevertheless, the basic reasons for the formation of latent images are not sufficiently understood and therefore further research should be carried out in this area.

REFERENCES

- 1 Close, D. H. 'Holographic optical elements', *Opt. Eng.* **14**, (1975) 408-419.
- 2 Kogelnik, H. 'Coupled wave theory for thick holograms gratings', *Bell. System Tech. J.* **48**, (1969) 2909-2947.
- 3 Solymar, L., Cooke, D. J. *Volume Holography and Volume Gratings*. Academic Press, London, (1981) Chap. 5.
- 4 Syms, R. R. A. *Practical Volume Holography*. Clarendon Press, Oxford, (1990) Chap. 5
- 5 Hariharan, P. *Optical Holography*. Cambridge University Press, London, (1984) Chap. 7.
- 6 Chang, B. J., Leonard, C. D. 'Dichromated gelatin for the fabrication of holographic optical elements', *Appl. Opt.* **18**, (1979) 2407-2417.
- 7 Kirsch, J. C., Gregory, D. A., Hudson, T. D., Lanteigne, D. J. 'Design of photopolymer holograms for optical interconnects applications', *Opt. Eng.* **27**, (1988) 301-308.
- 8 Rhee, U., Caulfield, H. J., Shamir, J., Vikram, C. S., Mirsalehi, M. M., 'Characteristics of the Du Pont photopolymer for angularly multiplexed page-oriented holographic memories', *Opt. Eng.*, **32**, (1993) 1839-1847.
- 9 Upatnieks, J., Leonard, C. D., 'Diffraction efficiency of bleached photographically recorded interference patterns', *Appl. Opt.*, **8**, (1969) 85-89.
- 10 Latta, J. N. 'The bleaching of holographic diffraction gratings for maximum efficiency', *Appl. Opt.*, **7**, (1968) 2409-2416.
- 11 Van Renesse, L. 'Advances in bleaching methods for photographically recorded holograms: Comments', *Appl. Opt.*, **14**, (1975) 1763-1764.

- 12 Thiry, H. 'New techniques of bleaching photographic emulsions and its applications to holography', *Appl. Opt.*, **11** (1972) 1652.
- 13 Phillips, N. J., Porter, D. 'An advance in the processing of holograms', *J. Phys. E*, **9**, (1976) 631-634.
- 14 Phillips, N. J. 'The role of silver halide materials in the formation of holographic images', *Proc. SPIE*, **932**, (1985) 29-38.
- 15 Owen, M. P., Ward, A. A., Solymer, L. 'Internal reflections in bleached reflection holograms', *Appl. Opt.*, **22**, (1983) 159-163.
- 16 Beléndez, A., Pascual, I., Fimia, A. 'Influences of recording geometry parameters on diffraction efficiency in bleached silver halide transmission holograms', *J. Modern Opt.*, **39**, (1992) 1855-1861.
- 17 Hariharan, P. 'Bleached photographic phase holograms: the influence of drying procedures on diffraction efficiency', *Opt. Commun.*, **56**, (1986) 318-320.
- 18 Hariharan, P., Chidley, C. M. 'Photographic phase holograms: The influence of developer composition on scattering and diffraction efficiency', *Appl. Opt.*, **26**, (1987) 1230-1234.
- 19 Oliva, J., Pardo, M., Quintana, J. A. 'High SNR in bleached silver-halide holography', *Appl. Opt.*, **21**, (1982) 171.
- 20 Fimia, A., Pardo, M., Quintana, J. A. 'Improvement of image quality in bleached holograms', *Appl. Opt.*, **21**, (1982) 3412-3413.
- 21 Syms, R. R. A., Solymer, L. 'Planar volume phase holograms formed in bleached photographic emulsions', *App. Opt.*, **22**, (1983) 1479-1496.
- 22 Kostuk, R. K. 'Factorial optimization of bleach constituents for silver halide holograms', *Appl. Opt.*, **30**, (1990) 1611-1616.

- 23 Bjelkhagen, H. I. *Silver-Halide Recording Materials-for Holography and Their Applications*. Springer-Verlag. Berlin (1993).
- 24 Beléndez, A., Pascual, I., Fimia, A. 'Model for analyzing the effects of processing on recording material in thick holograms', *J. Opt. Soc. Am. A*, **9**, (1992) 1214-1223.
- 25 Beléndez, A., Pascual, I., Fimia, A. 'Efficiency of thick phase holograms in the presence of shear-type effects due to processing', *J. Modern Opt.*, **39**, (1992) 889-899.
- 26 Pennington, K. S., Harper, J. S., Laming, F. P. 'New phototechnology suitable for recording phase holograms and similar information in hardened gelatin', *Appl. Phys. Lett.*, **18**, (1971) 80-84.
- 27 Graver, W. R., Gladden, J. W., Eastes, J. W. 'Phase holograms formed by silver halide (sensitized) gelatin processing', *Appl. Opt.*, **19**, (1980) 1529-1536.
- 28 Chang, B. J., Winick, K. 'Silver-halide gelatin holograms', *Proc. SPIE*, **215**, (1980) 172-177.
- 29 Ferrante, R. A. 'Silver halide gelatin spatial frequency response', *Appl. Opt.*, **23**, (1984) 4180-4181.
- 30 Hariharan, P. 'Silver halide sensitized gelatin holograms: Mechanism of hologram formation', *Appl. Opt.*, **25**, (1985) 2040-2042.
- 31 Angell, D. K. 'Improved diffraction efficiency of silver halide (sensitized) gelatin', *Appl. Opt.*, **26**, (1987) 4692-4702.
- 32 Fimia, A., Pascual, I., Beléndez, A. 'Silver halide sensitized gelatin as a holographic storage medium', *Proc. SPIE*, **952**, (1988) 288-291.
- 33 Fimia, A., Pascual, I., Vázquez, C., Beléndez, A. 'Silver-halide sensitized holograms and their applications', *Proc. SPIE*, **1136**, (1989) 53-57.

- 34 Fimia, A., Beléndez, A., Pascual, I. 'Silver halide (sensitized) gelatin in Agfa-Gevaert plates: The optimized procedure', *J. Modern Opt.*, **38**, (1991) 2043-2051.
- 35 Pascual, I., Beléndez, A., Fimia, A. 'Reflection holographic optical elements in silver halide sensitized gelatin', *Opt. Appl.*, **21**, (1991) 239-244.
- 36 Fimia, A., Beléndez, A., Pascual, I. 'Influences of R-10 bleach on image latent formation in silver halide sensitized gelatin', *Appl. Opt.*, **31**, (1992) 3203-3205.
- 37 Fimia, A., Pascual, I., Beléndez, A. 'Optimized spatial frequency response in silver halide sensitized gelatin', *Appl. Opt.*, **31**, (1992) 4625-4627.
- 38 Simova, E. S., Kavehrad, M. 'Holographic 4x4 star coupler in silver-halide sensitized gelatin', *Opt. Eng.*, **32**, (1993) 2233-2239.
- 39 Chang, B. J. 'Dichromated gelatin as holographic storage medium', *Proc. SPIE*, **177**, (1979) 71-81.
- 40 Usanov, Y. E., Shevtsov, M. K., Kosobokova, N. L., Kirienko, E. A. 'Mechanism for forming a microvoid structure and methods for obtaining silver-halide gelatin holograms', *Opt. Spectrosc. (USSR)*, **71**, (1991) 375-379.
- 41 Fimia, A., Pascual, I., Carretero, L., Beléndez, A. 'Diffuse-object holograms in silver halide sensitized gelatin', *J. Modern Opt.*, **41**, (1994) *in press*.
- 42 Pascual, I., Beléndez, A., Fimia, A. 'A two step method for recording holographic optical elements with partially coherent light', *J. Opt.*, **22** (3), (1991) 135-140.
- 43 Pascual, I., Beléndez, A., Fimia, A. 'Holographic system for copying holograms with partially coherent light', *Appl. Opt.*, **31**, (1992) 3312-3319.

- 44 Beléndez, A., Pascual, I., Fimia, A. 'Imaging in white light with a thick-phase transmission holographic doublet', *J. Opt.*, **20** (6), (1989) 263-268.
- 45 Beléndez, A., Pascual, I., Fimia, A. 'Holographic enlarger with an afocal two-element system', *Opt. Appl.*, **22**, (1992) 219-223.
- 46 Beléndez, A., Pascual, I., Fimia, A. 'Holographic collimator of 200 mm diameter in silver halide sensitized gelatin', *J. Opt.*, **21** (5), (1990) 211-215.
- 47 Fimia, A., Fuentes, R., Pascual, I., Beléndez, A., Egozcue, J. J., Navarro, M.T. 'Copying computer generated holographic interconnects by the use of partially coherent light', *Appl. Opt.*, **33**, (1994) *in press*.

FIGURE CAPTIONS

Figure 1.- Schematic representation of postulated photochemical process.

Figure 2.- Postulated cross-linking process [39].

Figure 3.- Diffraction efficiency for SHSG process in Kodak plates and Agfa-Gevaert 8E75 HD plates, according to the processing schedule presented in Table I.

Figure 4.- Diffraction efficiency as a function of spatial frequency for PAAP and D-19 developers.

Figure 5.- Diffraction efficiency as a function of exposure for different bleaching temperatures.

Figure 6.- Diffraction efficiency as a function of exposure for different water bath temperatures before and after the bleaching step.

Figure 7.- Diffraction efficiency as a function of the concentration ratio between baths B and A of the bleaching (see Table I) for the developer PAAP.

Figure 8.- Diffraction efficiency as a function of spatial frequency, measured in the water step and after the final drying, for PAAP developer, with and without stop in the processing.

Figure 9.- Noise as a function of exposure for two grating-forming systems.

Figure 10.- Geometric set-up for measuring the noise in diffraction gratings.

Figure 11.- Noise as a function of exposure for two different developers.

Figure 12.- Noise as a function of exposure for two different bleaching temperatures.

Figure 13.- Diffuse-object geometry.

Figure 14.- Experimental set-up for recording diffuse-object holograms.

Figure 15.- Diffraction efficiency, transmittance and signal-to-noise ratio (SNR) as a function of density before bleaching for diffuse-object holograms and for the D-19 developer.

Figure 16.- Diffraction efficiency and reconstruction wavelength for maximum diffraction efficiency as a function of exposure, for reflection gratings processed according to Table III.

Figure 17.- Diffraction efficiency and reconstruction wavelength for maximum diffraction efficiency as a function of the concentration of dichromate in the bleaching bath, when concentration of bromide 35 g/l remains constant.

Figure 18.- Diffraction efficiency and reconstruction wavelength for maximum diffraction efficiency as a function of the concentration of bromide in the bleaching bath, when concentration of dichromate 2 g/l and sulfuric acid 10 cc/l remain constant.

Figure 19.- Transmittance as a function of reconstruction wavelength for reflection gratings processed according Table III.

TABLES

Table I.- Processing scheduled for SHSG.

Table II.- Processing scheduled for dichromated gelatin.

Table III.- Processing scheduled for SHSG modified according to ref. 39.

FIGURE 1
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FIGURE 18
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FIGURE 19
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TABLE I

STEP

- 1.- Develop for 4 minutes (D-19, AAC).
- 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 (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 20 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.
- 10.- Dry in vacuum chamber.

Note: All solutions at 20°C except the bleaching step

AAC DEVELOPER FORMULA

1-Ascorbic acid	18	g
Sodium carbonate	60	g
Distilled water to make	1	liter

BLEACH FORMULA

<i>Solution A:</i>	Distilled water	500	ml
	Ammonium dichromate	20	g
	Sulphuric acid	14	ml
	Distilled water to make	1000	ml

<i>Solution B:</i>	Potassium bromide	92	g
	Distilled water to make	1000	ml

Just before use, mix one part A with ten parts distilled water, then add x parts B, according to the text

TABLE II

STEP

Preparation of plates

1.- Soak in fixer (done in dark)	15 minutes
2.- Rinse in running water (done in dark)	15 minutes
3.- Rinse in methyl alcohol	10 minutes
4.- Rinse in clean methyl alcohol	10 minutes
5.- Dry in vertical position	> 6 horas

Sensitizing plates (done in red light)

6.- Soak in ammonium dichromate in flat pan (emulsion side up)	5 minutes
7.- Tilt plate ~10° and allow excess to run off	3 minutes
8.- Remove residue at edge with a paper towel	
9.- Store in light tight box with same tilt until ready to use	
10.- Dry in ambiental conditions	15-40 horas

Developing plates

11.- Rinse in running water (done in dark)	20 minutes
12.- Dehydrate in 50 per cent isopropanol	3 minutes
13.- Dehydrate in 90 per cent isopropanol	3 minutes
14.- Dehydrate in 100 per cent isopropanol	3 minutes
15.- Dry by baking at 65°C	20 minutes

FIXER FORMULA: $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ 10%

SENSITIZING FORMULA: Ammonium dichromate 0.5 %

Plates Kodak 649 F

TABLE III

STEP

- 1.- Develop with Kodak developer PAAP 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 (for formula see below).
- 4.- Stop to high humidity (90%) for 24 hours
- 5.- Rinse in running water for 30 seconds.
- 6.- Soak in fixer F-24 for 2 minutes.
- 7.- Wash in running water for 10 minutes.
- 8.- Dehydrate in 50% isopropanol for 3 minutes.
- 9.- Dehydrate in 90% isopropanol for 3 minutes.
- 10.- Dehydrate in 100% isopropanol for 3 minutes.
- 11.- Dry in vacuum chamber.

Note: All solutions at 20°C except the bleaching step

BLEACH FORMULA

<i>Solution A:</i>	Distilled water	500	ml
	Ammonium dichromate	20	g
	Sulphuric acid	14	ml
	Distilled water to make	1000	ml
<i>Solution B:</i>	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.