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POLARIZATION INFLUENCE ON THE SIGNAL TO NOISE RATIO IN BLEACHED SILVER HALIDE DIFFUSED-OBJECT HOLOGRAMS

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ABSTRACT

The efficiency of diffuse-objects holograms recorded in bleached silver halide emulsion is analyzed as a function of the polarization state of the readout wave. An important source of noise founded in this holograms, when they are processed with rehalogenating bleaches, are noise gratings which are very sensitive to polarization. The dependence of signal-to-noise ratio on the relative polarization between the construction and reconstruction beam is showed too. Experimental results are presented which permit to choose the better conditions of reconstruction of this holograms.

Keywords: Holographic recording materials, noise, silver halide emulsions, polarization.

1. INTRODUCTION

An ideal holographic recording reconstructs a wavefront whose complex amplitude is linearly proportional to that of the original signal wavefront. Properties of the recording causing light other than that proportional to the signal to diffract into the direction of the signal wave may be regarded as sources of noise. The dielectric holograms typically reconstruct a brigther image than absorption holograms, but these holograms have greatly reduced contrast, or higher noise level. This decrease of quality is caused by a number of factors, some of which are inherent in the characteristics of dielectric recording and some of which are caused by imperfections of the recording material. We can presumably improve the recording materials, but we cannot entirely eliminate the noise inherent in the dielectric recording process. This can be reduced by the proper choice of recording parameters and chemical processing.

In several important aplications of holography such as optical interconnects or optical information storage is necessary to multiplex several functions or optical components in the same thin film recording material. An optically recorded multiple grating hologram can be encoded either sequentially or simultaneously, but for the same total exposure, the diffraction efficiency of sequentially recorded hologram is less than a simultaneous hologram. If the number of multiplexed gratings is increased, and the angles between these gratings are reduced, the recorded object beam should resemble the field from a diffuse-object[1]. On the other hand, the theoretical maximum storage density (bit per unit hologram area) in an ideal (noise-free) thick hologram, is proportional to the hologram thickness[2]. However, in actual holograms the noise is presents and it is a serious limitation to that density, due to that, the maximun storage density is a function of the signal-to-noise ratio (SNR) of the hologram. By all this reasons it is important to analyze the characteristics of diffuse-object holograms, in the field of optical interconnects[3] or information storage[4,5].

The recording material that we used was silver halide emulsions because this is an important medium for testing holographic concepts. This is due to the relatively hight sensitivity and ease of processing of this material, improved processing of chemistries and the repeatability of the results. A fundamental limitation of the holograms recorded in photographic emulsions is the scattering of light from the silver halide grains[6], wich takes place both at the recording and at the reconstruction stages. During formation of a hologram, object fields scattered by the silver halide grains of the photographic emulsions interfere with the unscattered portion of the illuminating beam (which works as a reference beam), and because this, spurious gratings are recorded in the medium[7]. During the reconstruction stage of the hologram, these self-induced gratings (called noise gratings) diffract light in directions other than the direction of the signal beam, and this gives rise to a reduction in the diffraction efficiency and in the quality of the intentionally formed hologram.

During the step of reconstruction of the holograms too it is produced scattering of light from individual grains of the processed photosensitive medium in which the hologram is formed. This source of noise namely "scattering"

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becomes important when the diffraction efficiency is low. Low diffraction efficiency is unavoidable when the hologram plate must be exposed briefly to a weakly reflecting subject or when a larger number of absortption holograms are sequentially superimposed on the same plate[8]. However, in the experimental work that we have developed, the object beam came from a transilluminated square glass diffuser and only one exposure is given on the plate, moreover we obtained phase holograms. Thus, this source of noise is not relevant.

An important source of noise in dielectric diffuse-object hologram is intermodulation noise, which is a random-phase pattern that is caused by the self-interference of light from an extended object[9-11]. This phase structure is recorded as a variation of the refractive index within the emulsion and as a variation of the thickness of the layer because of the relatively low frecuency of the pattern, i.e. while the signal beam was recorded on a carrier that can be considered volume recording, the intermodulation noise usually span both the two dimensional and volume -recording, but basically it is two dimensional.

There is other type of noise that can be produced in phase holograms, it is a result of the intrinsic nonlinearity of these holograms[12]. As an example of this, consider the simple case in which the final phase modulation, $\varphi(x)$, to be imposed on the illuminating wave is simply proportional to de exposure $E(x)$, say $\varphi(x)= \gamma E(x)$, where is a proportionality constant between exposure and phase modulation. The amplitude transmittance, T_a, defined as the ratio between the light amplitude transmitted and the light amplitude incident at the plate is given by :

$$T_a(x) = T_0 \exp(i \gamma E(x))$$

where T_0 is the average transmittance.

Most of the effect of this nonlinear relation between amplitude transmittance and exposure is to produce diffraction orders higher than the first. These orders are diffracted at angles that are two or more times the angle of the desired first-order image and thus are usually well separated from it. The existence of higher-order images is generally not important as long as they do not overlap the first-order images. The criterion for prevention of overlap is that the spatial bandwidth of the holographic signal modulating the carrier should be less than one-third the carrier frequency[13]. In our case this criterion is fulfilled as the incidence angle of the reference beam was 37.5° and the extreme points of the object formed an angle from the central point of the plate of 3.8°. At this form, the carrier frecuency was ≈1000 l/mm and the modulater frecuency was ≈100 l/mm, which is one-tenth of the carrier.Therefore this source noise have been elliminated.

Therefore, the main surces of noise which will have the reconstructed image of the diffuse-object will be noise gratings and intermodulation noise.

The polarization properties of thick hologram gratings are due to the different values of the coupling between the diffracted and incident waves inside the hologram for different directions of the electric vector of the incident wave, but this properties are more pronounced at hight spatial frequencies than at low[14]. It must be taken into account that the intermodulation noise is a low-frecuency noise and therefore it is little sensitive to changes in the direction of the electric vector. That fact will be experimentally demonstrated in this paper.

On the other hand previous papers[15,16] have reported the influence of polarization on noise gratings but the study have been done using a single collimated beam or two collimated beams. In other paper we showed[17] the presence of noise gratings in diffuse-object holograms as an important source of noise. However the analysis of the influence of polarization on noise gratings in diffuse objects holograms have not been contemplated in any paper up to the present time.

The aim of the present paper is to present experimental results of the influence of the polarization angle (defined as the angle between the polarization vectors of the construcion and reconstruction beams) on the diffraction efficiency, the noise and the signal-to-noise ratio of diffuse-objects holograms recorded in bleached silver halide emulsion.

2. EXPERIMENTAL

Holograms of diffuse-object were formed by the interference of a collimated beam polarized perpendicular to the plane of incidence (reference beam) and a object beam came from of a uniformly transilluminated square glass diffuser 2 cm x 2 cm with an opaque 1cm x 1cm square in the center. The distance of the object from the recording medium was 30 cm and the reference beam formed a 37.5° angle with the normal of the holographic plate which was parallel to the object. The reference-to-object beam ratio was 9. These beams were produced by an He-Ne laser at a wavelength of 632.8 nm and Agfa Gevaert 8E75HD photographic emulsion was used.

Twelve holograms were made with exposures ranging from 10 to 340 μJ/cm^2. Spurious reflections were eliminated by placing of an index-matched absorbing layer against the glass side of the photographic plate. The exposed plates were developed in PAAAC developer, which consists of a solution of sodium carbonate (120 g), ascorbid acid (18 g) and phenidon (0.5 g) in 1litre of distilled water. The developed plates were rinsed briefly and bleached without a fixation step. Two types of bleach baths were used in these experiments: One was R-10 and the other was EDTA. Both of they are rehalogenating bleach baths. R-10 was composed of potassium dichromate (2 g), shulphuric acid (10 ml) and potassium bromide (35 g) diluted in 1litre of distilled water. EDTA was composed of ferric sulfate (30 g), potassium bromide (30 g), shulphuric acid (10 ml), diluted in 1litre of distilled water. The resulting emulsion thickness change introduced with these rehalogenating baths is very small (<0.05 μm) in the nominally 6 μm thick film[18]. Also it is assumed that the average refractive index does not change appreciably as a result of processing[18]. As thickness and the average refractive index of the holographic recording material show very little change when these chemical processing are used, the reconstruction geometry of the holograms corresponding to maximum diffraction efficiency will coincide with the construction geometry if recording and readout wavelengths are equal. This implies that Bragg's Law will be complied with in the reconstruction stage.

Processed holograms were replayed by the conjugate of the collimated reference wave, and the diffracted output beam formed the real image of the object. The diffraction efficiency and the signal-to-noise ratio (SNR) were measured as a function of the replay angle using the same wavelength that was used during the recording stage. Measurements were obtained at 1-degree increments around the angle of the reference beam. The signal was measured as the ratio between the average maximum light intensity in the square ring of the reconstructed object and the incident light intensity and the noise was measured as the ratio between the minimum light intensity in the central squared of the reconstructed object and the incident light intensity. Therefore the SNR tell as the contrast at the reconstruted object. In all cases the experimental mesurements were corrected taking into account the losses due to the reflection at the two surfaces of the plates .

The plane defined by the emulsion surface normal and the electric field of the recording beam was used as a reference for polarizations of the recording and the replay beams. It is defined a polarization angle[9] δ , so that $\delta = 0°$ for the polarization of the reconstruction beam parallel to the polarization of the construction beam and $\delta = 90°$ when polarizations of the construction and reconstruction beams are perpendicular.

3. RESULTS AND DISCUSSION

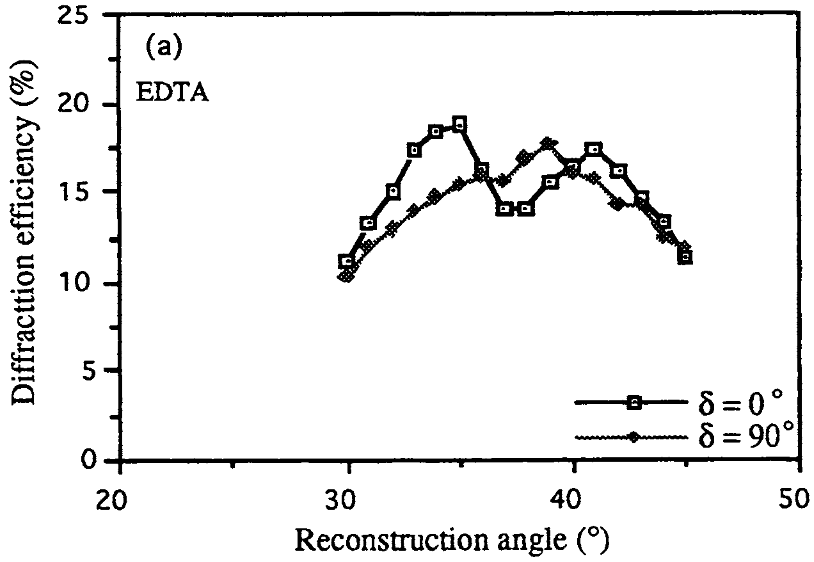
Figures 1a and 1b show curves plotted for the diffraction efficiency as a function of the reconstruction angle for plates processed with EDTA and R-10 respectively. In this figures the pronounced drop in diffraction efficiency at the construction angle 37.5° when $\delta = 0°$ is caused by the presence of the noise gratings. It is observed furthermore that the angular response of the diffraction efficiency is symmetrical around recording angle for EDTA but not for R-10. In the last case there is a little displacement in the angular response which is not centered in the reference angle. As the thickness and the average refractive index of the emulsion have not changed with the processing used, this displacement in the angular response could be caused by shear-type effects[20]. When the reconstruction is done with $\delta = 90°$ it is noticed that the dip at the Bragg angle is elliminінated and the diffraction efficiency in this case is greater than with $\delta = 0°$ but this do not ocurr always but it depends both the exposure as the processing.

As it can be seen in Figure 2a y 2b, when we reconstructed the holograms with the Bragg angle the diffraction efficiency when $\delta = 90°$ was clearly greater than when $\delta = 0°$ from 120 μJ/cm^2 for EDTA, Figure 2a, and from 30 μJ/cm2 for R-10, Figure 2b.

Moreover it is important also to observer that if a different diffraction efficiency is obtained from this exposures for each polarization it can be due to have recorded an anisotropic periodic structure into the holographic emulsion.

Curves for the noise as a function of the reconstruction angle appear in Figures 3a and 3b for plates processed with EDTA and R-10 respectively. We can see clearly that when $\delta = 90°$ the image has more noise than when $\delta = 0°$. The measured noise with the two processing is similar when $\delta = 0°$ but when $\delta = 90°$ it is larger with R-10 than with EDTA. That can be due to that when $\delta = 90°$ the predominant source of noise is intermodulation noise which is a low-frecuency noise and therefore it is very sensitive to emulsion thickness variations and therefore to the mechanism of material transfer. The diffusion coefficient[21] of R-10 is greater than EDTA and therefore amplificates better the modulation of low-frecuncy. This is the reason for obtain a peak noise for R-10 larger than for EDTA.

It is also important to observe that at the reference beam there are a pronounced drop when the reconstruction is done with $\delta = 0°$, in the same way that diffraction efficiency.



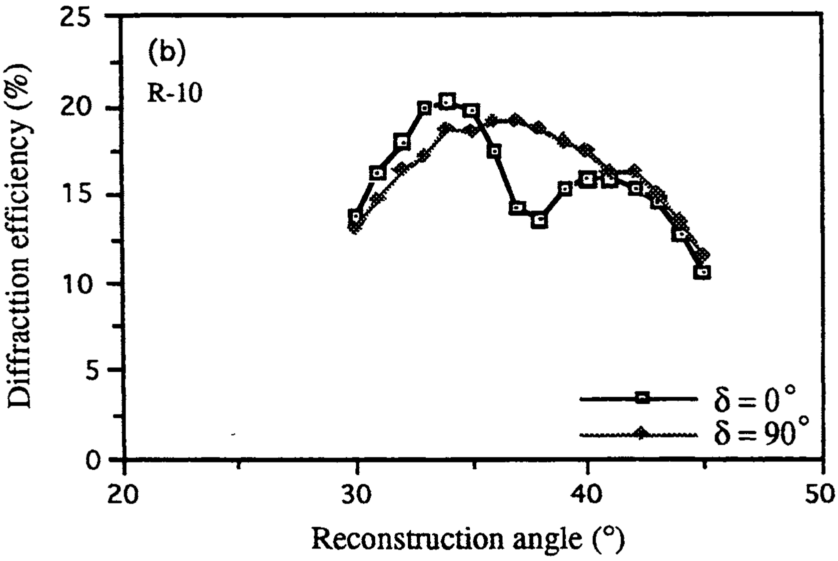


Figure 1.- Diffraction efficiency as a function of the reconstruction angle, when a level of exposure of 70 $\mu J/cm^2$, for two values of δ and two different processing: (a) EDTA, (b) R-10.

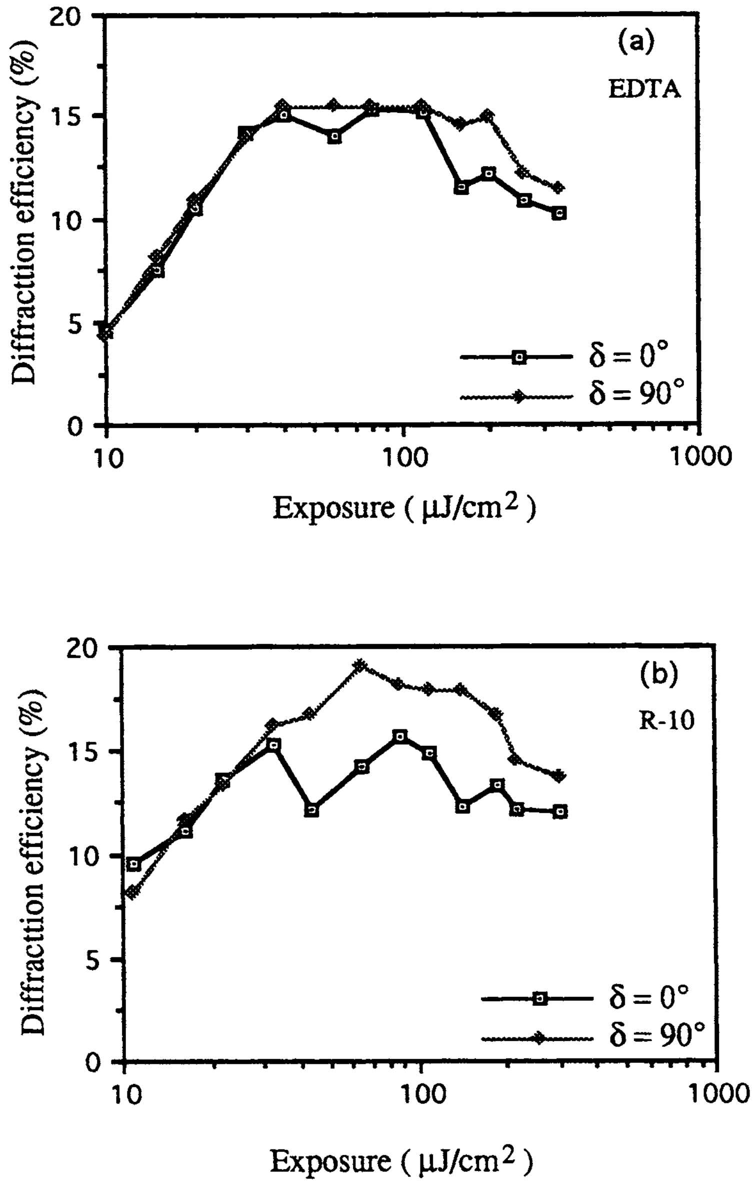
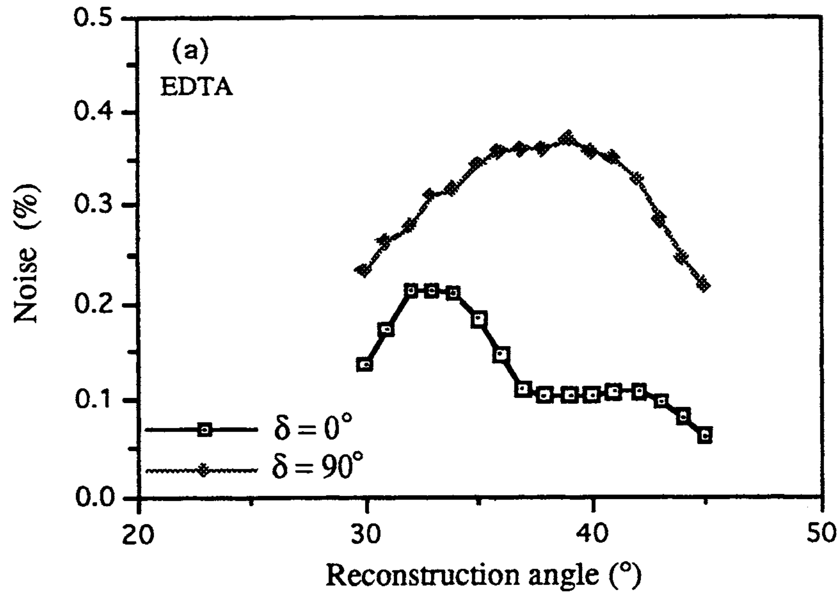


Figure 2.- Diffraction efficiency as a function of the exposure when the reconstruction angle was the Bragg angle and for two different processings: (a) EDTA, (b) R-10.



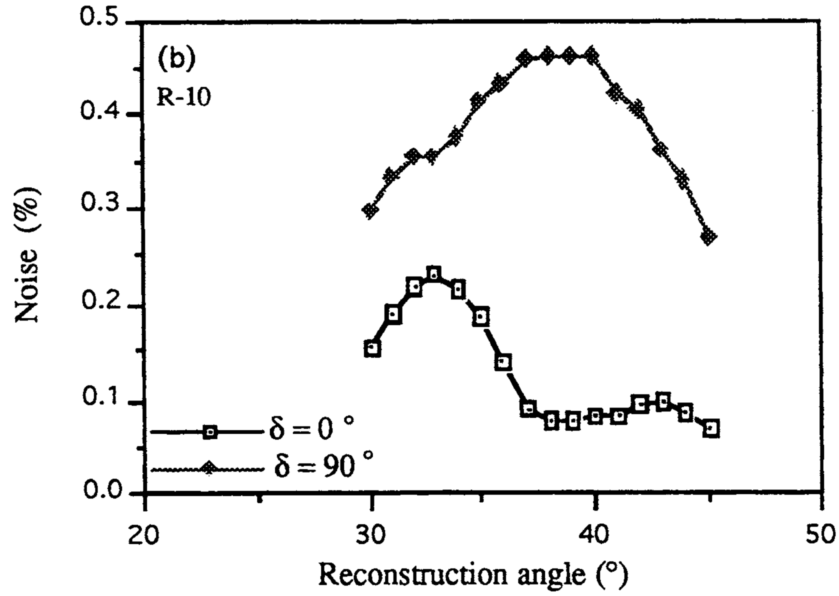


Figure 3.- Noise as a function of the reconstruction angle when the level of exposure was 70 $\mu J/cm^2$, for two values of δ and two different processing: (a) EDTA, (b) R-10.

Therefore the noise gratings are very sensitive to polarization however it was sayed before that intermodulation noise is little sensitive to changes in the direction of the electric vector. That can be experimentally confirmed when the used processing has a fixation step because in this case there are no noise gratings [17] and the main source of noise is intermodulation noise.Throught Figure 4 it can be see the result.

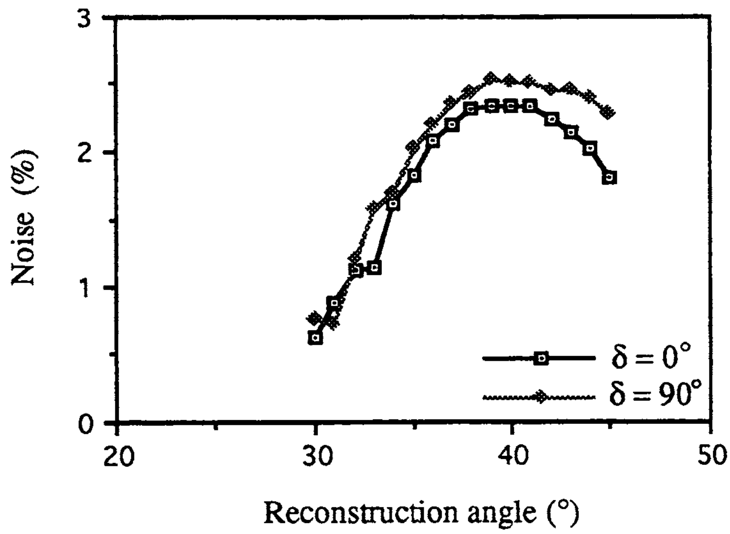
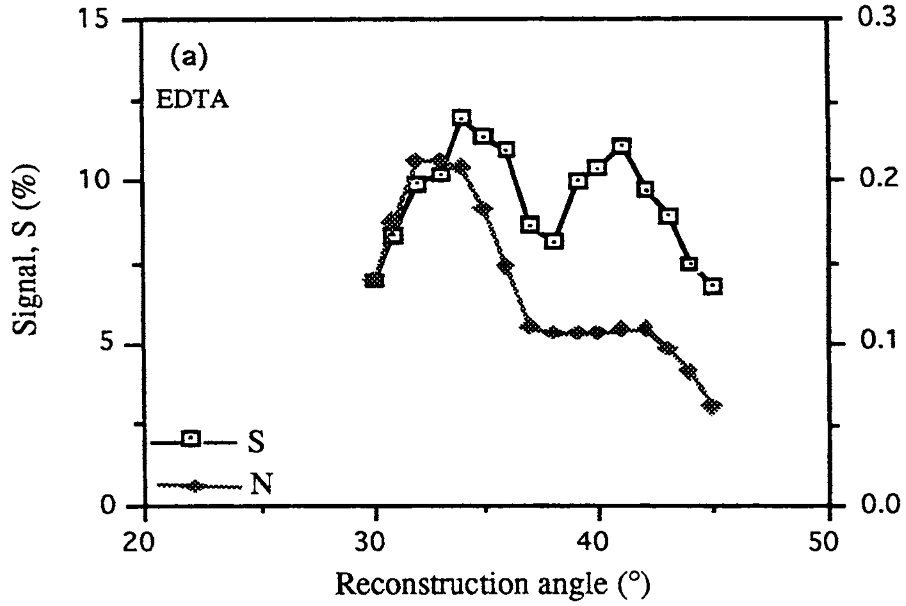


Figure 4.- Noise as a function of reconstruction angle when the level of exposure was 70 μJ/cm^2 and when the processing had a fixation step previous to the bath bleaching.

Figures 5a and 5b shows both the signal and the noise as a function of the reconstruction angle for EDTA and R-10 respectively when δ = 0° and it can be observed that there are some reconstruction angles (from 38° to 41°) in which the signal increase but not the noise. This uncouply between the signal and the noise produces an increase both the SNR as the diffraction efficiency, which is an very important fact. This do not occur when δ = 90° as can be seen in Figure 6a and 6b for none processing. From this results it is deduced that hight values both SNR as diffraction efficiency will be obtained when the reconstruction angle be between 38° and 41° and when δ= 0° be fulfilled.



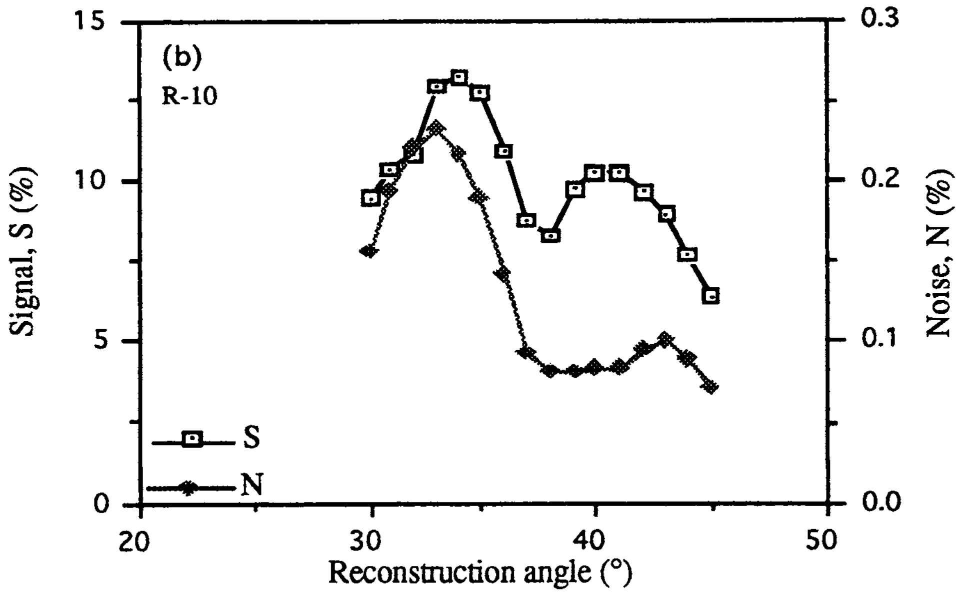


Figure 5. -Signal and noise as a function of reconstruction angle when he level of exposure was 70 μJ/cm^2 and δ=0°. The used processing were (a) EDTA and (b) R-10.

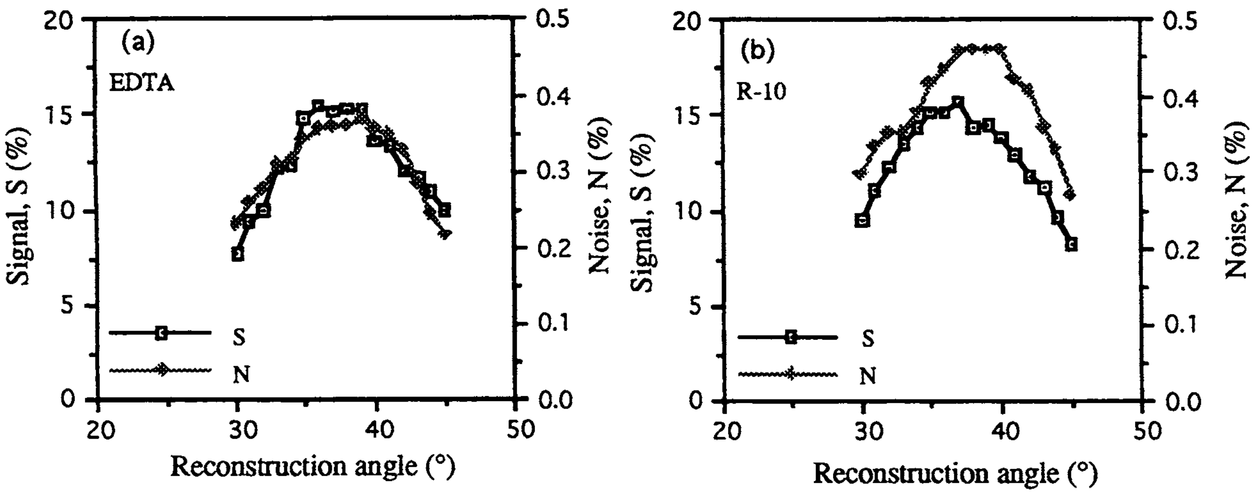
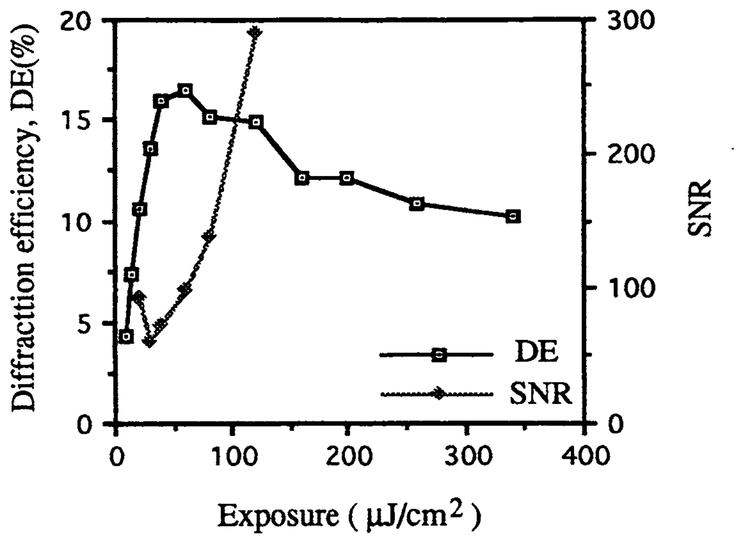


Figure 6.- Signal and noise as a function of reconstruction angle when he level of exposure was 70 μJ/cm^2 and δ=90°. The used processing were (a) EDTA and (b) R-10.

Finally, we analyze the variation of SNR and diffraction with the exposure when δ= 0° and when the reconstruction angle is 41° because it is expected this parameters to have the best values with this angle. The Figure 7a and 7b reflect the founded information when EDTA and R-10 are used respectively. It must take in mind that the value of noise was very small for exposures higher than 120μJ/cm^2 in the case of EDTA, then it could not measure with the photodetector . However, R-10 produced more noise and SNR could be measure until 180μJ/cm^2. Therefore with EDTA can be surely obtained better SNR than with R-10.



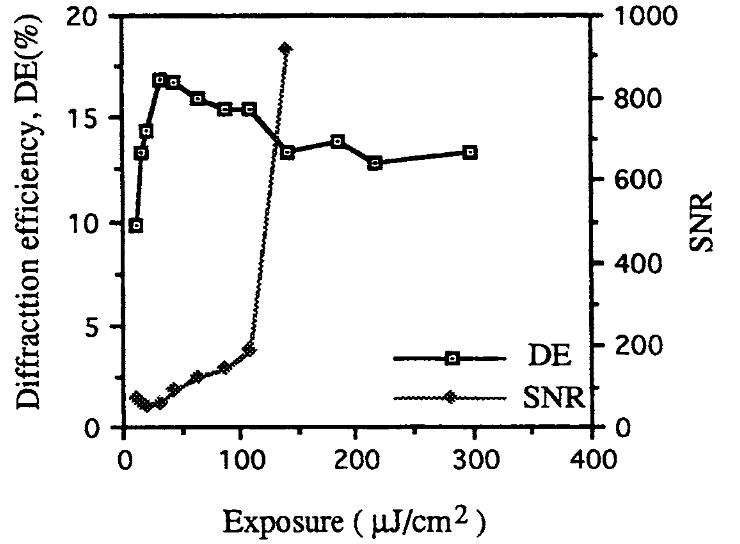


Figure 7.- Diffraction efficiency and signal-to-noise ratio as a function of exposure when the reconstruction angle was 40° and when δ=0°. The used processing were (a) EDTA and (b) R-10.

5. CONCLUSIONS

When the polarization of the reconstruction beam is perpendicular to the recording beam, the diffraction efficiency of a bleached diffuse-object hologram, reconstructed in the Bragg angle, is higher than when the the two polarizations are parallel only from a particular value of exposure which depends of the processing used.

On the other hand, although the change of polarization in the reconstruction produces the elimination of a source of noise (the noise gratings) the recostructed image is more noisy.

Other important result is that when the reconstruction is done with the same polarization that during the recording, there are a set of reconstruction angles, larger than the Bragg angle, in which the signal increase but not the noise. This fact produces an simultaneous increasement both the signal-to-noise ratio and the diffraction efficiency.

Finally, the experimental results of this paper are important when holograms for optical storage[4,5] or optical interconnections are recorded[3].

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