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Abstract. The holographic gratings on photopolymer films are studied by three different thicknesses for samples A, B, and C. The photopolymer emulsion is prepared with potassium dichromate and nickel (II) chloride hexahydrate in polyvinyl alcohol matrix. The evolution of diffraction efficiency is evaluated during holographic recording with and without voltage as a function of energy exposure by changing the thickness. The curves of diffraction efficiency reach a peak when the films are continuously exposed to energy for a period of time. Sample B obtains the highest diffraction efficiency
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Subject terms: holography; holograms; materials; photopolymer; gratings.

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1 Introduction

Interference recording of two shortwaves in a holographic media modifies some of the optical properties of materials such as conductivity and refraction index.[1] Formation of the hologram takes place when the photo-initiator is excited by the illumination pattern, resulting in the formation of radicals. These highly reactive compounds produce a spatially nonuniform polymerization and as a result of the concentration gradients produced, monomers diffuse from the dark regions to the neighboring bright regions. Thus, the spatial modulation of the refractive index and its evolution over time is the result of nonuniform polymerization and the diffusion monomers. The temporal variation of diffraction efficiency depends on the temporal conversion grade of monomer into polymer, so depending on the termination process the response of the diffraction efficiency will be different in function to some physical and chemical parameters, such as concentration of photo-initiator, monomer, or intensity.[2]

After holographic irradiation of the photopolymer is interrupted at an early stage of the conversion, the thermal post-polymerization enhances the spatial modulation of segment density between bright and dark areas that goes along with an increase of the modulation of the refractive index and an improvement of the diffraction efficiency. The key phenomenon is the balance between the chemical initiation of the polymerization and the diffusion of unreacted species from nonlight struck areas to bright regions of the record.[3]

The voltage effect is reported as a stabilizer way to reach the saturation self-enhancement.[4] We have studied the *p*H effect and aging of coating emulsions for hologram recording[5] and analyzed the diffraction efficiency study of holographic gratings in dichromated polyvinyl alcohol $NiCl_2 \cdot 6H_2O$ doped.[6] We have previously reported that preliminary results respect the voltage effect to holographic recording using only a specific thickness film using a different type of substrate (3M-PP2900^{TM}) and an other optical setup for diffraction efficiency reading. However, the experimental data presented in this manuscript has new parameters for the study of diffraction efficiency such as more exposure energy and variation of the thickness film with and without voltage application due to the fact that the thickness is an important parameter in holographic storage to determine the sensitivity and the capacity of storage. The thickness parameter is a nontrivial factor. Ions are released through the volume of material, and also the photosensitivity of image formation is determined by free ions in the volume of material. The free electron population through the material produces a competition between the ions: to record the image and to conduct electricity. The balance is the basis for both phenomena. This duality in the material makes it attractive for future applications.

2 Experimental Method

A photopolymer film is composed of polyvinyl alcohol (PVA, Meyer®), potassium dichromate (DCP, Baker®), nickel (II) chloride hexahydrate (Ni, Baker®), and glycerol (Gly, Meyer®). This photosensitive material is prepared with aqueous solutions of each component PVA (7% wt), DCP (10% wt), and Ni (10% wt). Each solution is stirred, mixed, and heated step by step for a duration of 45 min to dissolve powder and crystals. The photosensitive solution was prepared adding 1 ml of DCP solution, 1 ml of Ni solution, and 40 μl of glycerol in 6 ml of PVA solution. The mixture was stirred and mixed well to get a homogeneous solution. The dichromate polyvinyl alcohol nickel (II) chloride hexahydrate (DCPVANi) solution was poured on the clean leveled substrate to get a photosensitive film. The substrate used in this experiment is glass (Lauka®) which has a thickness of $\pm$ 1 to 1.2 mm and the area of the plates is 1456 mm^2. Table 1 shows three types of samples depending of the volume's film. The amount of solution poured on the substrate is determined such as a function of the desired thickness of the sensitive layer.

The coating solution on the substrate is covered to prevent dust particles from falling on the film. The drying time for the photosensitive layers is 24 h by the gravity settling method. The photosensitive composition is sandwiched between glass covers and there are two copper electrodes. The thickness film is measured by a Digimatic Micrometer

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Table 1 Classifications of samples by thickness of photosensitive emulsion.

Volume ratio (ml)	Samples		Thickness (microns)
		A	330
1:6:1	DCP:PVA:Ni	B	770
		C	1045

(Mitutoyo Corporation® Model IP65). The preparation of the coating solution and films are prepared at room temperature in the laboratory. The relative humidity is 42 to 63% and the temperature is 18 to 24°C.

The optical symmetrical setup to record the holographic gratings and read the diffraction intensity is shown in Fig. 1. The recording laser beam of He-Cd "LR" (Melles Griot®, 50 mW, $\lambda = 442$ nm) is moderately attenuated by a filter "F" and it is divided into two different intensity beams "IR1" and "IR2" by a beam splitter. The intensities are not equal. The mirrors "M1" and "M2" are used to direct respective beams upon the sample causing interference between them. Interfering beams cause modulation of refractive index. The diffracted light is measured by the He-Ne laser "Lr" (Melles Griot®, 30 mW, $\lambda = 632.8$ nm). The intensity of the diffracted beam "Ir(+ 1)" is measured at first order by a detector "D." The diffracted beam is measured during hologram formation as a function of time exposure but diffraction efficiency is reported as a function of exposure energy.

The angle of the scan beam "Ir" from He-Ne laser was 0 deg which was at normal incidence (see Fig. 1) with respect to the normal of the photosensitive sample surface DCP-VANi. The reading beam used to perform the corresponding

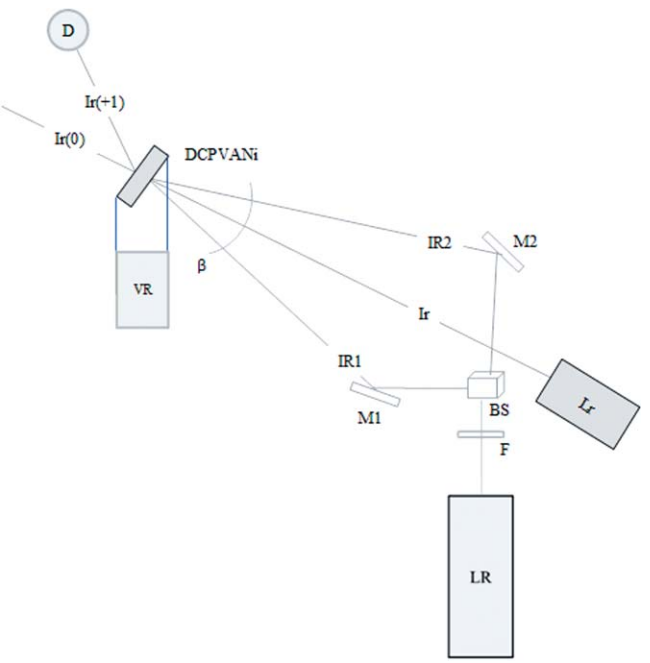

Fig. 1 Optical symmetrical setup to record holographic gratings at real time.

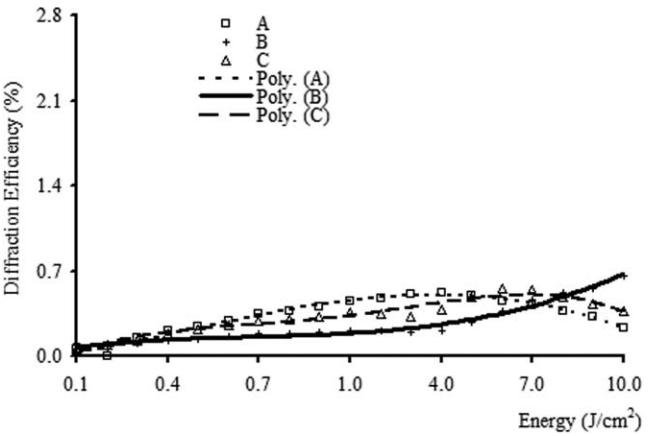

Fig. 2 Evolution of diffraction efficiency without voltage application (0 V).

measurements was in the first order diffracted "Ir(+ 1)" (see Fig. 1) by the gratings formed with the photosensitive material in real time.

The experiment is carried out with and without voltage application by diverse thickness of films. Power source "VR" (BK Precision®) of dc voltage is connected to the sample and it is regulated until the maximum value of 30 V. The angle between two intersecting recording beams is 26.6 deg which corresponds to spatial frequency of 726 lines/mm.

3 Results and Discussion

3.1 *Results Without Voltage*

Diffraction efficiency is analyzed varying the thickness film as a function of energy exposure. The experimental data during holographic recording without voltage application is reported in Fig. 2 where the thickness films of 330, 770, and 1045 μm correspond to sample A, B, and C, respectively. Curves A and C reach a diffraction efficiency peak of 0.5% for 4 J/cm^2 and 0.5% for 7 J/cm^2, respectively then both curves start to decrease. Curve B continues increasing and the maximum value of diffraction efficiency is 0.7% which corresponds to 10 J/cm^2. Figure 2 illustrates how the diffraction efficiency curves grow when the exposure energy

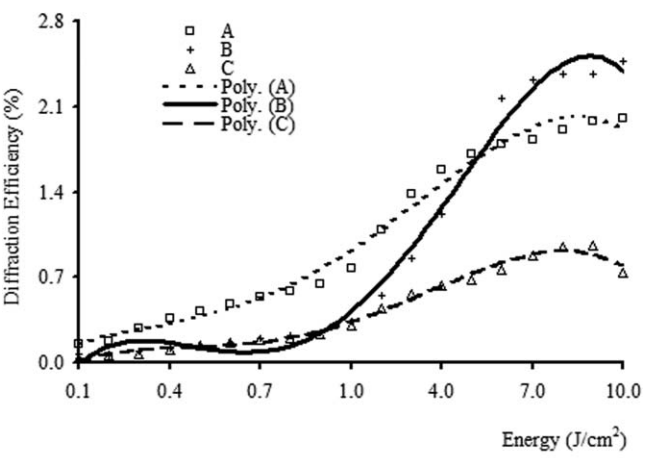

Fig. 3 Evolution of diffraction efficiency with voltage application (30 V).

increases achieving the saturation for sample A and C. For this period of energy exposure, the curve for sample B does not yet reach the saturation which means samples A and B have more sensibility than sample C.

3.2 *Results with Voltage*

Experimental data evolution with voltage application is illustrated in Fig. 3 where the diffraction efficiency curves to samples A, B, and C represent the diffraction efficiency for thickness film of 330, 770, and 1045 microns, respectively. The three curves achieve the saturation point that is to say that each curve reaches a peak and then start to decrease. The maximum values of diffraction efficiency are reported for sample A of 2% and sample B of 2.5%, both of them to 9 J/cm^{2,} and for sample C is 0.9% to 8 J/cm^2. In general, the curves of diffraction efficiency increase quickly by voltage application and these values are bigger than the respective curves shown in Fig. 2.

4 Conclusions

- From the study of diffraction efficiency with and without voltage application, it concludes that the best diffraction efficiency values are reached with voltage application to the photosensitive films during holographic recording.
- The evolution of diffraction efficiency varying the thickness of the film is determined with or without voltage application but in both cases, sample B represents the optimum thickness to register holographic grating with the maximum values of diffraction efficiency.

The results show the response of the photosensitive material using potassium dichromate and nickel (II) chloride hexahydrate like an electron donor agent which can be balanced. An important point for this process is the fact that the salt hexahydrate helps the PVA matrix, due its hydrophilic properties, which leads to having a balanced mix. The qualities of these materials include support for building a photosensitive emulsion and also with the ability to conduct electricity.

The thickness parameter is a nontrivial factor for obtaining good results, and sample *B* with a thickness of 770 μm is obtained with the diffraction efficiency of 2.5% with a potential of 30 V. No voltage is obtained 0.7% of diffraction efficiency. It is clear that the electrodes to the emulsion, was oriented perpendicular to the grooves, which were formed by the interference pattern in the arrangement of Fig. 1. Obviously, these types of emulsions with these qualities do not show diffraction efficiencies as high as conventional holograms display that shows a duality result: the ability to record holographic images and at the same time the capability to file a response in the presence of an applied voltage of low intensity. This opens new opportunities in generating innovation diffractive optical elements which can be modulated by a voltage signal.

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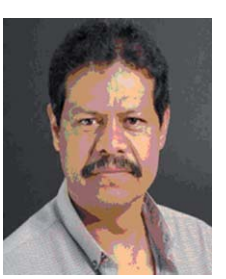

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