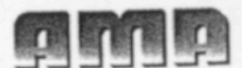




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HOLOGRAM RECORDING IN PHOTOPOLYMERS BY MEANS OF CONTINUOUS LASER EXPOSURE

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Photopolymers may be considered holographic recording materials because of their many attractive features. Among such features, we could mention their ability to self-develop, the fact that dry processing can be used with them, their good stability and thick emulsion layers, together with their high sensitivity, diffraction efficiency and resolution. Photopolymers have been developed for conventional imaging systems, real time interferometry and holographic optical elements. These materials have applications in other optical devices such as high-density storage and optical data processing. This paper is a study of a PVA/acrylamide photopolymer as a holographic recording material when a continuous laser is used.

It is well known that holography enables an image to be reconstructed in three dimensions, as opposed to photography in which the image is reproduced in only two dimensions. However, this characteristic is not the most technically useful in other fields of science and technology. Thus, for example, the characteristic on which the development of basic elements in sectors such as communications and computers is based is the ability to divert, in free space at any desired angle, a beam of incident light onto a point of the plate on which the hologram is recorded. Such holograms are known as holographic optical elements [1]. Another characteristic of holography that enables the development of areas such as information storage [2] is the capacity to store many object waves in a single hologram when volume holographic elements are used.

In the manufacture of holographic optical elements, as well as in the storage of information, the key factor is the utilization of an appropriate recording material. There is a great demand for holographic recording materials capable of giving impetus to each of the various applications, such as optical memories [3-5], optical processing [6] or holographic interferometry [7]. It is therefore necessary to make further advances in the development of holographic recording materials, since the success of modern optical devices depends on the behavior and versatility of the optical material employed.

The demand for better recording materials requires that they have characteristics such as high resolution, high energetic sensitivity, great spectral sensitivity, simple processing and erasure of information.

This present study is centered on an analysis of the behavior of a photopolymer employed as a holographic recording material when a continuous laser is used. In the first place, all aspects related to obtaining and depositing the photopolymeric material - preparation of the final solution, depositing, uniformity of the dry film and its characteristics such as thickness and transmittance - are considered. In the second place, the behavior of the photopolymer is analyzed from the holographic point of view, considering the diffraction efficiency achieved and sensitivity of the stored holograms.

The recording material used is composed of a matrix of polyvinylalcohol (PVA), acrylamide (AA) as monomer, triethanolamine (TEA) as radical generator and yellowish eosin (EA) as sensitizer. Two types of photopolymerizable solutions were prepared, each of them using a different type of PVA: one supplied by Riedel-de-Haen, with a molecular weight of 25000, and the other by Fluka, with a molecular weight of 130000. In previous studies [8, 9] we worked with the Riedel-de-Haen PVA only, but this company recently ceased production of its PVA and so it is important to determine the holographic differences between the two types of holographic plates considered.

Experimental.

The photosensitive solution is prepared by adding 2 ml of a 8g/l aqueous solution of yellowish eosin (supplied by Panreac) and 6.4 ml of a solution of acrylamide (supplied by Sigma) and triethanolamine (supplied by Sigma) to 40 ml of polyvinyl alcohol in water. The concentration of each of the components can be seen in Table 1.

	Riedel	Fluka
ACRYLAMIDE (AA)	0.45 M	0.45 M
TRIETHANOLAMINE (TEA)	0.20 M	0.20 M
YELLOWISH EOSIN (YE)	2.5×10^{-4}	2.5×10^{-4}
POLYVINYLALCOHOL (PVA)	10 %	2% - 8%
40 ml solution		

Table 1: Composition of the photosensitive solution.

The resulting solution is coated, using an automatic depositor, on a 20 x 40 cm² glass plate to give an initial thickness of 500 μm. The plate is dried for 24 hours in the dark under normal laboratory conditions (T ≈ 19-23 °C, RH ≈ 40-50 %) and subsequently cut into plates measuring 6.5 x 6.5 cm². The thickness of the layer was measured with a PIG 455 apparatus supplied by Neurtek. The final thickness of the dry film depends on the concentration of PVA employed.

One of the problems arising is that of obtaining layers with a specific, uniform thickness. The thickness of the photopolymer film is of fundamental importance in the recording of holographic gratings. According to Kogelnik's theory [10], the thickness determines the temporal evolution of diffraction efficiency. Variations in thickness produce changes in the shape of the diffraction efficiency versus time curves, in the position of the maximum diffraction efficiency reached, and in the sensitivity of the material, which increases with thickness.

To study the behavior of the photopolymer as a holographic recording material, we obtained diffraction gratings using a holographic setup. The experimental device is shown in figure 1. An Argon laser at a wavelength of 514 nm was used to store diffraction gratings by means of continuous laser exposure. The laser beam was split into two secondary beams with an intensity ratio of 1:1. The diameters of these beams were increased to 1 cm with an expander, while spatial filtering was ensured. The object and reference beams were recombined at the sample at an angle of 16.8° to the normal with an appropriate set of mirrors, and the spatial frequency obtained was 1125 lines/mm. The working intensity at 514 nm was 5 mW/cm². The diffracted intensity was monitored in real time with a He-Ne laser positioned at Bragg's angle tuned to 633 nm, where the material does not absorb.

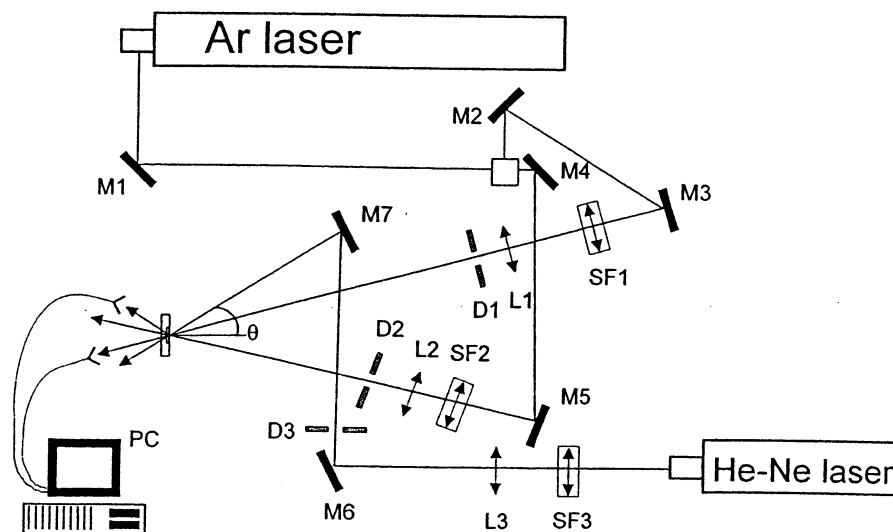


Figure 1. Experimental setup: BS, Beamsplitter, Mi, mirror, Sfi, spatial filter, Li, lens, Di,

diaphragm, PC, personal computer.

Results and discussion.

We stored holographic diffraction gratings using holographic plates obtained with two types of PVA. The Fluka PVA has an average molecular weight of 130000, whereas that of the Riedel PVA is around 25000. The viscosity of aqueous solutions of the two PVAs is also different. A 4% solution in water at 20 °C has a viscosity of between 4 and 6 mPa*s in the case of Riedel PVA and from 16 to 20 mPa*s in the case of Fluka PVA. This difference in the viscosity of the solutions has proved to be a crucial factor in the depositing of layers. The greater viscosity of solutions of Fluka PVA means that, for a standard concentration of 10% w/v and a rod of 500 microns in the automatic depositor, it is a factor which limits the final thickness of the deposited layer. The high viscosity of this solution of Fluka PVA makes it necessary to use the apparatus at its lowest velocity of depositing so as to give the material sufficient time to flow under the rod, since as it is more viscous it does not flow as easily as the Riedel PVA. However, the lowest velocity possible with the automatic depositor is not low enough and the material is mainly swept along in front of the rod instead of flowing under it so as to form the deposited layer. Consequently, some of the solution is not deposited on the glass plate. In the case of Riedel PVA, the lower viscosity of a 10% w/v solution means that this factor is not limiting when a rod of 500 micras is used, and a velocity of depositing close to the minimum of the apparatus is ideal for the solution to be correctly deposited with minimum loss. A possible solution would be to modify the concentration of Fluka PVA and use concentrations of below 10%.

Therefore, we carried out a study of the holographic behaviour of Fluka PVA, varying the percentage of PVA used to deposit the layer of material. We studied the diffraction efficiency and sensitivity of the material when holographic diffraction gratings were stored on photopolymer plates obtained using percentages of Fluka PVA of between 2% and 8%.. The results can be seen in figure 2.

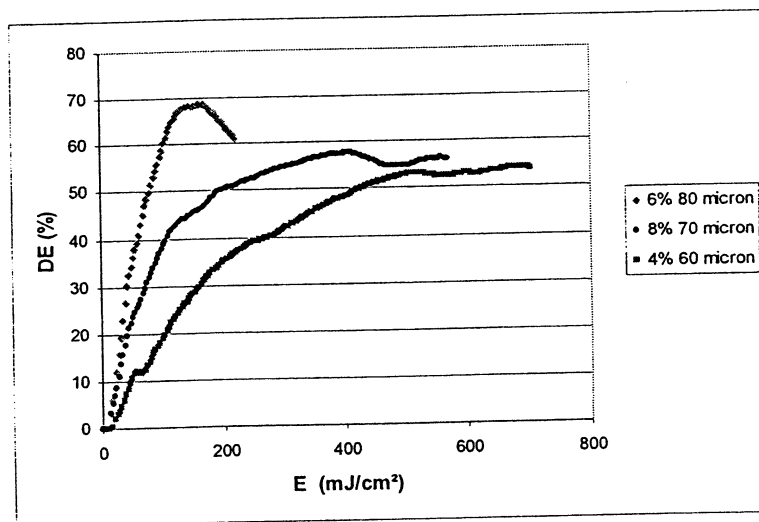


Figure 2: Diffraction efficiency (DE) versus exposure (E) for different concentrations of Fluka PVA and different thicknesses.

Firstly, it can be seen that the holographic behaviour of the material varies depending on the percentage of Fluka PVA. When a 4% solution is used, mean thicknesses of around 60µm are obtained and so efficiencies of only 50% are reached. When the percentage of Fluka PVA is increased, the mean thickness of the deposited layer increases, resulting in higher diffraction efficiencies – as high as 70% with a 6% concentration of Fluka PVA and a thickness of 80µm.

When the concentration of Fluka PVA in the initial solution deposited is decreased, the viscosity decreases and the solution is swept along by the rod to a lesser extent, so less solution is lost at the sides and end of the plate. In fact, with 6% Fluka PVA the thickness of the final layer is greater than with 8% Fluka PVA, since less solution is swept along and lost by running off the plate. Therefore, although a 6% solution is less viscous and tends to occupy a greater surface area than an 8% solution, this is compensated for by the fact that less solution is swept off the plate by the rod. If we decrease the concentration of Fluka PVA

further, the flow of the solution along the rod is no longer a limiting factor and the effect of a lower viscosity predominates. Therefore solutions with less than 6% PVA are even less viscous and tend to occupy a greater surface area, with the result that more solution is lost at the sides and end of the plate.

Bearing in mind that the sensitivity of a holographic recording material is defined as the minimum energy necessary to reach maximum diffraction efficiency, from figure 2 it can be seen that the sensitivity is greater when the thickness of the plate is increased.

Since we are considering mean thicknesses, it is possible to find variations in thickness in the same plate. Therefore, it would seem logical to choose a specific thickness obtained using different concentrations of PVA, so as to determine the most suitable concentration for the formation of photopolymer plates

Figure 3 shows the diffraction efficiencies achieved by photopolymer plates 90µm thick obtained using different concentrations of Fluka PVA. As can be seen, the best value of 85% is reached with concentrations of between 4% and 6%. The sensitivity in this case for a diffraction efficiency of over 70% is between 200 and 400 mJ/cm², since all the plates have the same thickness of 90µm.

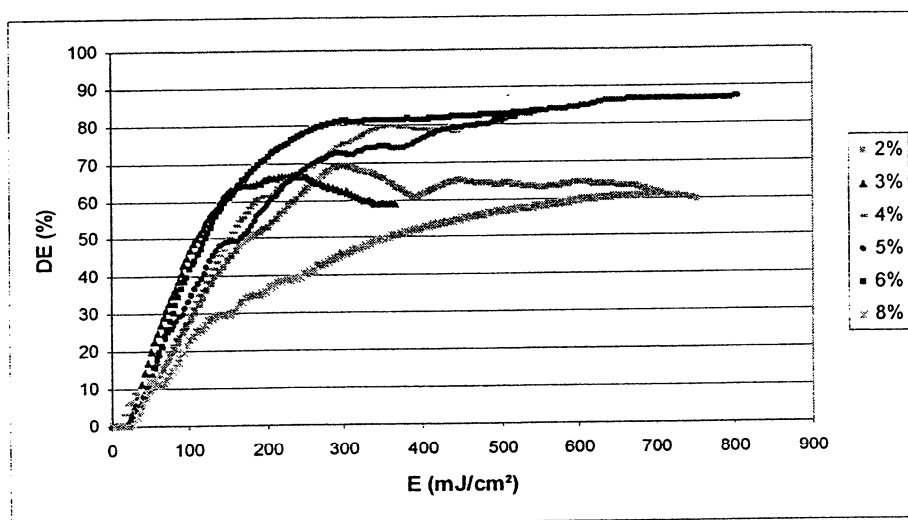


Figure 3: Diffraction efficiency (DE) versus exposure (E) for different concentrations of Fluka PVA and the same thickness.

When the concentration of PVA is decreased, the acrylamide exhibits a greater tendency to crystallize. This is due to the fact that there are fewer PVA molecules obstructing the formation of crystals and also less residual water retained by the dry film. Variation in the relative humidity and manipulation affect plates with a lower concentration of PVA to a greater extent, so they crystallize more easily thus rendering the material inapt for use as holographic recording material. In addition, it has been verified that once the diffraction grating is stored, crystallization in the areas exposed to the laser does not progress due to the fact that this area is occupied by the formed polymer and so the concentration of free acrylamide is not sufficient for crystallization to take place. Therefore, once the hologram is stored, crystallization of the material may not be a problem, although it could cause the plastic film to break. Therefore, we believe that the optimum concentration of Fluka PVA to obtain holographic materials that enable the highest diffraction efficiencies to be reached and have the lowest possibility of crystallizing is 6%.

Finally, figure 4 shows the results obtained with Fluka PVA compared with those obtained with Riedel PVA. The photopolymer plates used were obtained with the optimum concentration of each PVA - 6% for Fluka and 10% for Riedel. As can be seen, the results obtained with Fluka PVA are not only comparable with those obtained with Riedel PVA in terms of diffraction efficiency (70%) for the same thickness (70µm), but also it is possible to reach higher diffraction efficiencies (80%) for thicker layers (90µm), using lower intensities of around 5 mW/cm² as compared with the 10 mW/cm² used when exposing the layers of photopolymer obtained using Riedel PVA. With regard to energetic sensitivity, we can see that the Fluka and Riedel PVA plates have a similar sensitivity, around 200 mJ/cm².

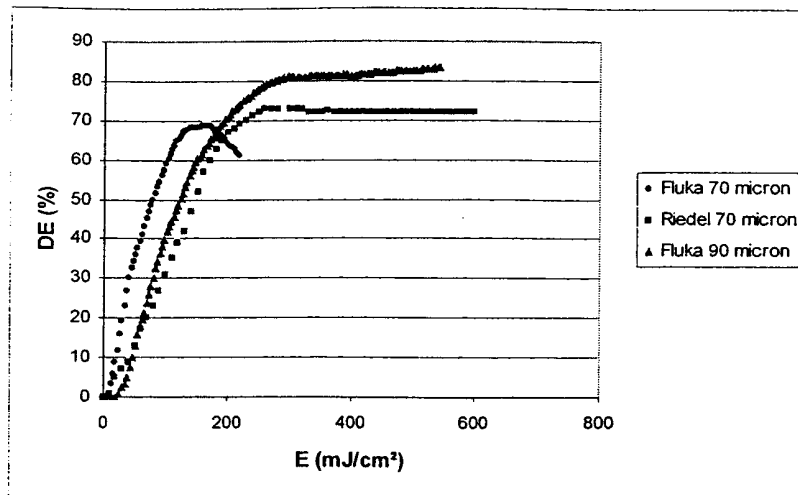


Figure 4: Diffraction efficiency (DE) versus exposure (E) for different PVA.

Therefore, we can conclude that photopolymer plates obtained using 6% Fluka PVA may substitute for photopolymer plates obtained using Riedel PVA, since from a holographic point of view they enable a slightly better results to be achieved.

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