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Polarized Phase Holograms of High Diffraction Efficiency

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Abstract

Holography has a wide application in medicine, optical computers, scanners among others. Conventional studies on analogue holograms have mainly been conducted on image generation, processing and reconstruction. However, these conditions may vary thus affecting hologram quality. Since convection holography uses photosensitive recording interference patterns in holographic material, there is a need to evaluate aberration or how high intensity of light has been reconstructed. In this paper, we analyzed the fundamental parameters such as exposure time and processing chemical composition effect in phase holograms. Optimization of these parameters resulted in phase hologram image of approximately 16% diffraction efficiency at an exposure time of 20 s. Moreover, the influence of objective beam polarization is investigated. The results show that by varying the polarization orientation, diffraction efficiency and fringe visibility are greatly affected. Polarized phase hologram of diffraction efficiency of 21.1% has been achieved.

Subject Areas

Applied Physics

Keywords

Polarization, Hologram, Diffraction Efficiency

1. Introduction

The invention of holography by Denis Gabor in 1948, has been the most prominent method in obtaining three dimensions (3D) images of an object [1] [2] [3]. The technique involves the recording of the interference patterns of the diffracted wavefronts from an object (object beam) and reference wavefronts on a photosensitive material [4] [5]. Upon processing of the photosensitive material a 3D image of the object is replayed by illuminating it with the same reference beam used during the recording process [4] [6] [7] [8] [9]. Apart from imaging, holography emerged as a potential technique for other applications such as in data storage, optical elements, and as a means of performing precise interferometric measurements on three-dimensional objects of any shape and surface finish [10].

However, the divergence potential application of holography has been limited noise leading to low quality (diffraction efficiency) hologram. To obtain holograms of high diffraction efficiency strict measures have to be adhered to. They include the use of a highly coherent source of light which has been achieved via invention of laser, low vibration surface to ensure stability of the fringes and proper composition of the developer among other requirements. If these requirements are not met there are possibilities of compromising on holographic imaging quality and limited spatial resolution [8].

In phase based holograms the amplitude information is disregarded. As a result, the quality of hologram image is greatly compromised. To overcome the limitation polarization photosensitive materials have been investigated with an aim of improving the quality of the hologram quality [11] [12] [13] [14] [15]. In addition, adaption of polarization holography has been reported as a means of enhancing holography applications [16] [17].

In this paper, we present a noble way of improving the diffraction efficiency of phase holograms. In our study, the optimization conditions for the recording of the phase holograms as well as processing have been achieved. This has led to obtaining phase hologram of approximately 16% diffraction efficiency at a processing period of 20 s. Polarization holography has potential applications in numerous areas such as high-capacity data storage, polarization-controlled optical elements, and other related fields. By manipulating polarization orientation of the objective beam from 0˚ to 90˚ holograms diffraction efficiency has been greatly improved to about 21% at 45˚.

2. Experimental Set-Up

2.1. Holograms Recording and Processing

The hologram recording set up is shown in **Figure 1**. The recording of the holograms was carried out in a darkroom. This was done at a time when all the light sources were blocked, the movements within the room minimized and temperature equilibrium attained. The 1 Shilling Kenyan coin was placed in such a way that beam illumination was maxima and equalized at all parts of the coin. To record the hologram, a PFG-01 holographic plates of dimensions 102 mm × 127 mm was used. The plate was placed on a mount when the entire light source had been blocked with the emulsion side facing the direction of the beam source.

A 35 mW linearly polarized Helium Neon (He-Ne) Laser of wavelength 632.8 nm was used. The light beam from the He-Ne was spatially filtered and later split

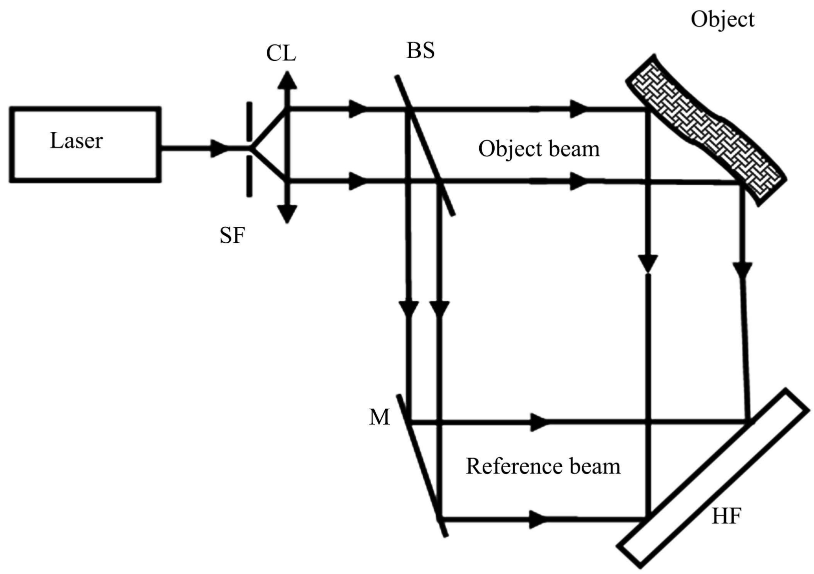

Figure 1. Schematic illustration of holographic recording set-up. SF is the Spatial Filter, CL is the Collimating Lens, BS is the Beam Splitter, HF is the Holographic Plate and M is reflecting mirror.

into two (object and reference) beams using a beam splitter. The object beam was the beam transmitted through the Beam Splitter and incident on the coin whose hologram was to be recorded. This beam was reflected to the holographic plate by the coin as depicted in Figure 1. The beam reflected by the beam splitter (the reference beam) was incident on the holographic plate. The set-up was allowed to stabilize for about two minutes before exposing the holographic plate.

To record the hologram, the two beams were superimposed on the holographic plate for some seconds. After the expose, the plates they were ready for processing using developing chemicals whose composition comprises of the developer and bleaching solutions as shown in Table 1 and Table 2 respectively.

The developing solution was prepared by mixing of part A and B (see Table 1). The mixture was dissolved using de-ionized water by stirred to obtain a homogeneous solution at room temperature. The exposed plate was immersed into the developing solution with the emulsion side facing upwards for 120 seconds and swirled in the solution during developing period. It was rinsed for 180 seconds and later dipped into a bleaching solution for 120 seconds. After bleaching using solution in Table 2, the holographic plate was dipped in photo flow solution for 30 seconds. The processed holographic plate was placed in an upright position for drying after processing.

In order to determine the quality of the hologram images formed, the reconstructed hologram was analyzed to determine its diffraction efficiency defined as [18]:

$$\eta(\%) = P_{\text{diffracted}} / P_{\text{incident}} \tag{1}$$

where η is the diffraction efficiency, $P_{\text{diffracted}}$ is power of the first order diffracted beam and P_{incident} is power of the incident beam.

Table 1. Developer chemical composition.

Component	Quantity
Part A: Pyrogallic acid	ns 10 g
Part B:sodium carbonate	60 g
Distilled water	1000 ml

Table 2. Bleaching solution composition.

Component	Quantity
Potassium dichromate	4 g
Sulphuric acid	8 ml
Distilled water	1000 ml

2.2. Polarization Effect on Hologram

The experiment involved the introduction of a polarizing beam splitter (PBS) on the reference beam path. This was done to generate the s-polarized and p-polarized beams. The power of the emerging s- and p-polarized beams from the reference beam was measured.

After determination of the emerging polarized beams, the PBS was withdrawn from the reference beam path and placed on the object beam path. The power of the emerging polarized beams of the object beam differed from that of the reference beam. To ensure that the polarization of the object beam and the reference beam were parallel to each other, a cellophane sheet whose property as a half wave plate (HWP) had been studied and verified was mounted on a rotatable holder and placed on the object beam before the PBS. The cellophane sheet was used to rotate the polarization of the linearly polarized object beam until its emerging s- and p-polarized light beams had the same polarization as the reference beam. On satisfying that the polarization orientation of the two beams was parallel, the PBS was replaced by a commercial Half Wave Plate (HWP) with its fast axis parallel to the cellophane sheet fast axis.

The set-up illustrated in Figure 2 was used to study the effect of polarization on hologram quality. Using the set-up plane wave transmission holograms were recorded as the commercial half wave plate was rotated at angles of 0.0˚, 22.5˚, 45.0˚, 67.5˚, and 90.0˚. The reconstructed holographic images were analyzed and their diffraction efficiencies determined.

3. Results

Exposing the holographic plate to the Laser beam causes a photochemical reaction that encodes information onto the holographic plate carried by the beam. To access the information, the development of the exposed plate was carried out. After processing of the exposed plate, it was inserted into the holographic plate holder and replayed. This was done by illuminating the processed holographic

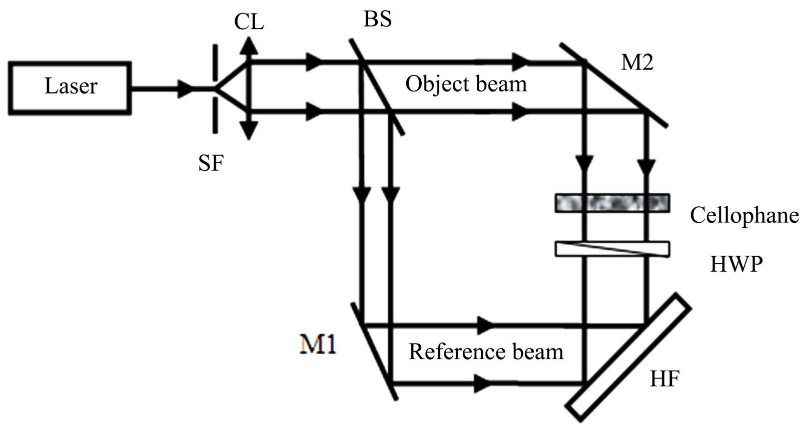

Figure 2. Schematic illustration of holographic recording set up used to investigate the effect of polarization. SF is the Spatial Filter, CL is the Collimating Lens, BS is the Beam Splitter, HF is the Holographic Plate, M1 and M2 are reflecting mirrors.

plate using reference beam. The reconstruction process affirmed the presence of successfully recorded hologram of the 1 Shilling Kenyan coin. The holographic images of the 1 Shilling Kenyan coin were captured using a 16.2 Megapixels Kodak digital camera. The photograph of the hologram image is shown in Figure 3.

To determine the best exposure time, the diffraction efficiencies variation was evaluated using Equation (1) as shown in Figure 4. At an exposure time of 10 s, 15 s, 20 s, 25 s and 30 s the diffraction efficiency was 9.8%, 13.4%, 15.8%, 12.9% and 9.5%, respectively. The results show that the best hologram was obtained an exposure time of 20 s.

To better understand the effect of the polarization angle on hologram quality a study was done. On evaluation of the recorded plane wave transmission holograms, a maximum diffraction efficiency of 21.1% and a minimum diffraction efficiency of 4.4% were obtained as illustrated in Figure 5.

The minimum diffraction efficiency value was recorded when HWP rotation angle was 45˚. At this angle the polarization of the object beam and the reference beam were orthogonal. The change in the diffraction efficiency of the hologram images recorded can be attributed to the decrease in fringe visibility. At a point where the transmission axis of the cellophane sheet and HWP were parallel, the diffraction efficiency was maxima. This translates to a high value of the fringe visibility.

To further verify the results, the hologram gratings were evaluated as shown in Figure 6(a) and Figure 6(b). The results show that depending on the noise level on the hologram grating, the diffraction efficiency of the hologram image was adversely affected.

In reference to the hologram diffraction efficiency, the noisy grating had low diffraction efficiency. The profiles obtained from each of the gratings also varied depending on the developer used. This method of hologram analysis is simple and convenient. Using the method, hologram development process can be studied thus giving a more compressive hologram image analysis.

Figure 3. Photographic images of a hologram of a 1 Shilling Kenyan coin.

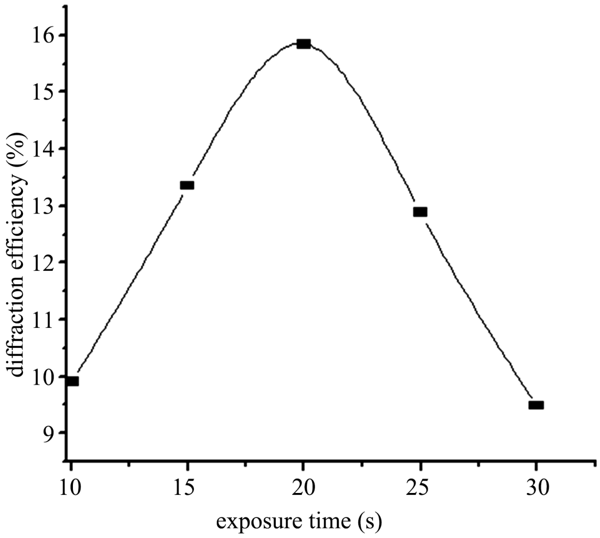

Figure 4. Shows diffraction efficiency as a function of exposure time for developer. The developer produces hologram image of 15.8% diffraction efficiency at an exposure time of 20 seconds.

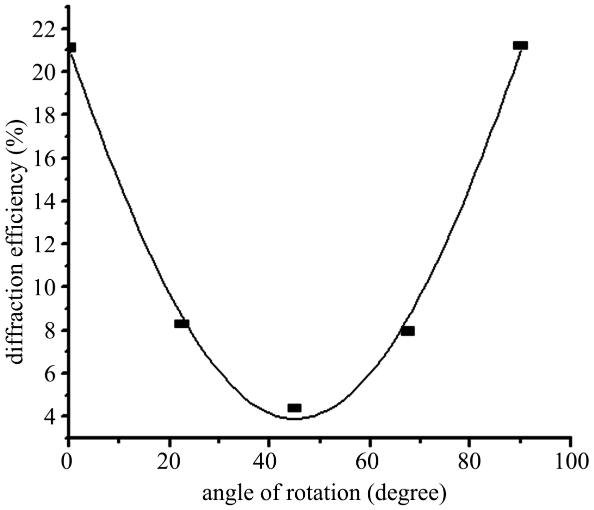

Figure 5. Shows diffraction efficiency as a function of HWP angle. The maximum diffraction efficiency of the hologram image was 21.1%. These maximum diffraction efficiency values were obtained at the angle of 0˚ and 90˚.

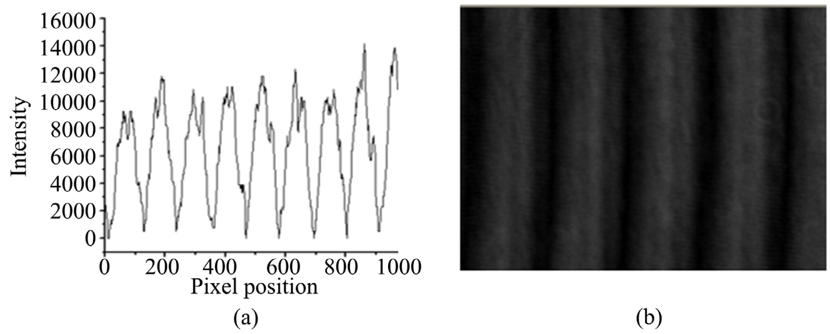

Figure 6. (a) The intensity profile of the hologram grating. (b) Hologram grating.

4. Discussion

The recording, processing and reconstruction of hologram require stringent measures to be observed. Fundamentally in all optical experiments, it is very important to ensure that the laser beam is parallel to the table or bench upon which the experiment is carried out. A well aligned Laser beam minimizes geometric aberrations which are a result of misaligned beam or optical component in the set up. Laser beam used in holography must be of single mode and highly coherent to satisfy production of quality holographic images.

Since the output from convectional Lasers is narrow, a lens could be used to expand the Laser beam to the desired diameter. However, the expanded beam could lose the smooth intensity profile. This could be contrary to the unexpanded beam oscillating in the TEM_{00} mode which was expected to exhibit a smooth Gaussian intensity profile. To overcome the challenge, laser beam spatial filtering was done. It's worth mentioning that for high diffraction efficiency hologram to be recorded fringe visibility must also be of high quality. In addition, the use of properly constituted hologram developer as well as processing period adversely determined the quality of the holograms. This is well demonstrated by the timing adopted in this work.

5. Conclusion

We have experimentally generated phase holograms and optimized the necessary conditions for obtaining high quality holograms with diffraction efficiency of approximately 16%. In addition, the effect of polarization on holograms has also been investigated. The results demonstrate that by varying the polarization direction of the laser beam diffraction efficiency of the hologram can be enhanced to about 21% thus diversifying the application opportunities for holography.

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Conflicts of Interest

The authors declare no conflicts of interest.

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