Leona Day

Experiments in Holography

The basic aspects of holography are examined by making three different holograms, a Gabor zone plate, a simple reflection hologram, and a transmission hologram. Once the exposure times for the film plates were adjusted, all three experiments were successful. The Gabor zone plate displays its properties of a thin lens with both positive and negative focal lengths. The reflection hologram came out extremely well and is practical as it can be viewed with a white light source. The transmission hologram, although successful, is very difficult to view and the image is not well centered. Further experiments could perfect this final hologram, attempt transmission holograms of larger and/or more numerous objects, and experiment with different experimental arrangements of the apparatus perhaps producing better holograms. Also, it would be fun to attempt making a cylindrical hologram.

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Introduction

The basic aspects of holography are examined through the creation of three different kinds of holography. A Gabor Zone plate was created which exhibits the properties of a thin lens with both positive and negative focal lengths. A very successful reflection hologram is made that can be viewed with a white light point source. A transmission hologram is also developed, although it is more difficult to view this one as it requires laser light at a special angle.

Theory

The difference between a hologram and a photograph is simply that the hologram carries information about the phase of the wave that created it in addition to the irradiance where a photograph simply carries the irradiance information. The phase information allows you to recreate the image that created the hologram in three dimensions where a photograph only allows for two.

Gabor Zone Plate

Gabor first created his zone plate, the original hologram, by photographically recording the interference pattern created by the interaction of scattered quasi-monochromatic light from an object and a plane wave reference beam. To create my Gabor zone plate we do the same thing but with one light source and a plano-convex lens. As the light from the light source, a diode laser, shines through the PCX lens, it reflects off of the two surfaces of the lens producing a circular fringe pattern. The interference pattern is the same as that Gabor originated except here, the plane wave reference beam is a result of the reflection from the flat surface of the lens. The reflection from the curved surface, which is acting as a spherical mirror, converges to a point at distance f from the zone plate and diverges as a spherical wave. The interference between this spherical wave and the plane wave generates the circular interference fringes on the film plate.

To actually create the hologram, the point source image is reconstructed by diffracting a coherent beam, I used the original laser beam, through the zone plate. The result is that the collimated light is diffracted into a beam converging to a real focal point at distance f from the plate that corresponds to the point at which the spherical wave from the PCX lens diverged to this point in front of the film. In addition, the zone plate produces a diverging beam that appears to result from the virtual image of the focal point on the other side of the plate at a distance f.

Mathematically, we can see the presence of the two focal lengths by looking at the transmission function for the plate. This function is given as

$$T(x,y) := constant + C_1\ exp\left(\frac{-ik\rho^2}{2f}\right) + C_1\ exp\left(\frac{ik\rho^2}{2f}\right)$$

The second term in the function is identical to the transmission function of a negative lens with focal length $-f$. The final term is the transmission function of a positive lens with focal length $+f$. So the zone plate acts as two thin lenses and has two simultaneous focal lengths.

Reflection Hologram[1]

Like the Gabor zone plate, this hologram is created by the interference of two waves. But this time, a three dimensional image of an extended object is created. Again there is a reference beam, which this time is the uncollimated, scattered light from the diode laser, but this time, we place the film plate directly in the path of the beam with the emulsion side facing away from the laser. The interfering wave, or the object beam, is the reflection of the laser light on the object. The object is situated just behind the film plate so that the plate is between it and the beam. The waves are now traversing the emulsion from opposite sides. The interference between the reference wave and the much more complex object wave creates a fringe pattern containing the irradiance and phase information describing the object. When white light is shone on the hologram, the resulting three-dimensional diffraction grating scatters the light back at the viewer and a virtual image is seen through the hologram as through a mirror.

Transmission Hologram[2]

The transmission hologram is similar to the reflection hologram in that an extended object is holographed through the interference of a reference beam and an object beam. However, the transmission hologram is capable of recording scenes with much greater depth than the reflection hologram. Here, as with the Gabor zone plate, there are two waves coming at the film plate from the same side, the emulsion side, of the plate. Like the reflection hologram, one of the beams that reaches the film is reflected off of the object and the reference beam is shown directly on the plate. This is achieved by offsetting the film to the side, slightly behind the object. Again, the two waves interfere and transmit a diffraction pattern containing irradiance and phase information of the object.

Experimental Method and Data

1. The Gabor zone plate was made using a diode laser, a collimating lens, a plano-convex lens and Slavich plates PFG-01 set up as shown in figure 1. The collimating lens that came with the diode laser was not used in this experiment; a wider beam is needed to produce the desired effect. The distance from

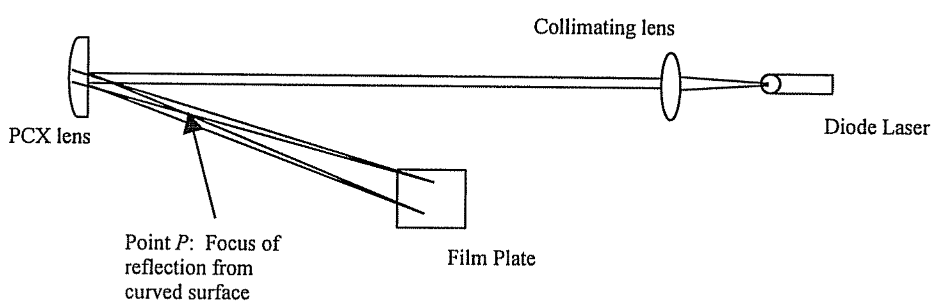

Fig. 1 Arrangement for creating zone plate.

the film plate to the focus created by the PCX lens was measured to be $f = 30.2$ cm so that a comparison between this distance and the distance between the zone plate and the reproduced image could be taken. The exposure time was calculated using the information on the Slavich plates found on their web site[3] and the information on the diode laser contained in Intergraf's Laser Holokit[4]. The diameter of the collimated laser beam is 2 cm.

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[1] See Hecht, Eugene. "Holography" Optics: 2nd Edition. Addison-Wesley Publishing Co.: Reading, MA. p. 602-4
[2] See Hecht, Eugene. "Holography" Optics: 2nd Edition. Addison-Wesley Publishing Co.: Reading, MA. p. 595-602
[3] Slavich – Emulsions for holography. Summary of technical specifications. http://www.slavich.com/tech_summary.html
[4] Laser Holokit-B. Integraf Products & Price List. http://members.aol.com/integraf/catalog.html

Film properties:

$$\text{resolution} := 3000\ \frac{\text{lines}}{\text{mm}}$$

$$\text{sensitivity} := 100\ \frac{\mu\text{J}}{\text{cm}^2}$$

Laser properties:

$$\text{power} := 0.5\cdot 10^{-3}\ \frac{\text{W}}{\text{s}}$$

$$\text{diameter} := 2\ \text{cm}$$

Exposure time:

$$\text{time} := \text{sensitivity}\cdot 10^{-6}\cdot\frac{4}{0.5\cdot 10^{-3}}\ \frac{\text{J}}{\text{cm}^2}\cdot\frac{\text{cm}^2}{\frac{\text{J}}{\text{s}}} \qquad \text{time} = \qquad \text{s}$$

Obviously a time of 0.8 s is a bit hard to be exact about in a dark room by myself but I was able to approximate "just under a second" and succeeded in taking two exposures. The first was did not work as well due to a slight misalignment resulting in an off-center projection of the plane onto the plate. After realigning the experiment, however, the second exposure produced the desired interference pattern. By placing this exposure in the same position in which it was taken, the point source *P* was found at a distance of approximately 30 cm from the plate as we expected.

2. The reflection hologram was created using the experimental set up described by Dr. Tung H. Jeong and Dr. Raymond J. Ro on the Integraf website[5]. No collimating lens was used and the laser beam from the diode laser was adjusted to spread out horizontally. The object to be holographed[6] was placed in

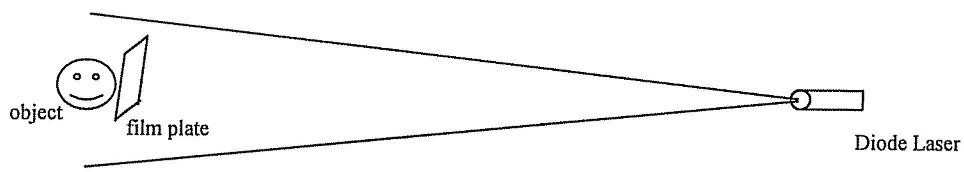

Fig. 2 Arrangement for creating a reflection hologram

front of the laser at a position where the light was spread evenly over the entire surface and it was optimally illuminated as shown below. It was necessary that the object be smaller than the film plate used to expose it. The film plate was then placed directly in front of the object, with the emulsion side facing and almost touching the object, and exposed for approximately 5 seconds as Jeong recommends. This produced an extremely dark image that was much over exposed so the experiment was repeated and the film was exposed for 5 short seconds instead of 5 long seconds. This second try produced the desired hologram that can be viewed using a simple flashlight.

3. The transmission hologram was exposed using Jeong's more detailed instructions which came with the holokit[7]. Again, no collimating lens was used and the object was fully illuminated. This time, due to the distance between the object and the film, a slightly larger object was used[8]. The film plate was placed at an angle of 45° to the reference beam again with the emulsion facing the object. The first exposure was taken for 10 seconds, as recommended by Jeong on his website[9] but the result was extremely dark so a second exposure was taken for less time (about 3 seconds) but this exposure was sorely underexposed. The third exposure, taken for a little over 5 seconds produced the desired result. This

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[5] Simple Holography. 4.3. Making a reflection hologram. http://members.aol.com/integraf/simpleholography.html
[6] A small angel given to my roommate Amy Bensle by her grandmother
[7] Jeong, Tung H., Ph.D. <u>Laser Holography: Experiments You Can Do...From Edison</u>. © 1987, Thomas Alva Edison Foundation, Inc. p. 13
[8] "Funky Shoe" a Christmas Gift from my friend Dianna Tucker
[9] Simple Holography. 5. Making a panoramic transmission hologram. http://members.aol.com/integraf/simpleholography.html

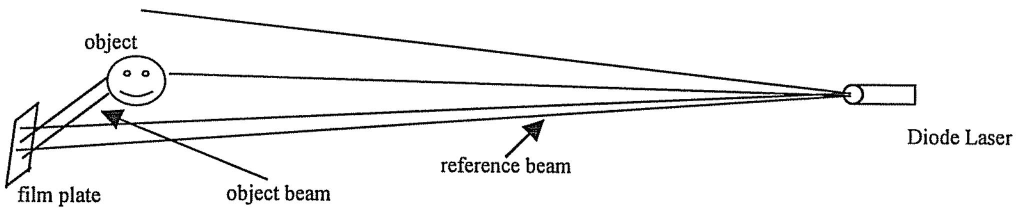

Fig. 3 Arrangement for exposing a transmission hologram

hologram is much harder to view than the reflection hologram. The developed film is placed in the same position in which it was taken and is viewed with the same laser light backward through the plate toward where the object was. The virtual image appears in the same place as the initial image. After finally figuring out how to view this object, I again looked at the first exposure and discovered that it wasn't as overexposed as I initially thought. Both the first and the third exposures produced a virtual image. However, the image is slightly off-center.

Developing

Each of the holograms was developed in the same way. Instead of using the developing chemicals that came with the holokit, regular photo developing chemicals were used. Kodak developer D-19 (CAT 146 4593) was used to develop the film. Each plate was left in the developer for 5 minutes. The plate was then put in a stop bath for 30 seconds. The stop bath used was Kodak indicator stop bath for film & paper (CAT 146 4247). After the stop bath, the plate was put in a fixer for another 5 minutes. Initially I was leaving the plates in the fixer for 10 minutes but as they were fine after 5, this precaution is probably unnecessary. I used Heico NH-5® High Speed Fixer without hardener and added Heico NH-5® Hardener following the instructions on the container. After the fixing the plates were rinsed in running water for anywhere from 10 – 30 minutes. This process produced quite acceptable results. Integraf's developing process includes a bleaching step that may be preferable to some who would want light holograms instead of the dark ones that the standard chemicals produce.

Conclusions

In conclusion, this was fun. The Gabor zone plate and the reflection hologram turned out quite nicely and the transmission hologram, though hard to view, is also an accurate reproduction of the object. If I were going to continue this project, I should first like to experiment more with the transmission hologram to see, first of all, if I can center the object in the film plate. Secondly I would like to experiment with different sized objects and greater distances from the film plate. I would also like to try more of the experiments Jeong details in his <u>Laser Holography</u> booklet, specifically, the cylindrical hologram.