HOLOGRAPHY: CREATING YOUR OWN ILLUSION

Lab Manual

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Purpose:

To understand the basics of holography through the creation of holograms using the direct beam, off-axis transmission procedure.

Reference:

Optics, Hecht, Ch. 13, Section 13.3 *Holography*. M.P.Givens *Introduction to Holography* Am J. Phys, **35** 1056-1064 .

Figures referred to by number in this write-up are in the description of the holography lab in the Fall 2000 lab manual.

Introduction:

The name "holography" is derived from the Greek word *holos* meaning "whole", the term *hologram* meaning "complete picture". A more descriptive term is "wavefront reconstruction" .

Discovered by the Anglo-Hungarian Dennis Gabor in 1948, holography only became a practical technique after the invention of the gas laser in 1961. It is a method of recording the amplitude *and phase* of a wavefront scattered from an object, and of using this record to reconstruct an image of the original object. A hologram stores on film the pattern of interference between by light coming directly from a laser (the reference beam) and light scattered from the laser beam by an object (the scattered beam). In order to view the hologram, the film has to be illuminated with the original reference beam or its equivalent. Under illumination, the interference pattern stored on the film acts as an extremely complex diffraction grating, and produces a diffracted beam that recreates for the observer the light that came from the object. Since what is stored is *all* the information contained in the wavefront created by the 3-dimensional object, rather than a two-dimensional projection of the intensity as in a conventional photograph, the holographic image is three-dimensional.

There are many different methods of making holograms. One thing they have in common is that the optical path difference (OPD) of the two interfering beams, measured from their common origin in the laser, must not exceed the coherence length of the source. For a multimode gas laser such as the one used in this lab the coherence length is in the region of 10-20 cm. In this lab you will use the off-axis method, in which the reference and scattered beams strike on the same side of the film from different angles. Wavefront division is used to separate the reference beam from the beam incident on the object, and to ensure that the OPD does not exceed the coherence length the object is back-lighted. The general set-up is shown schematically in Fig A on the next page.

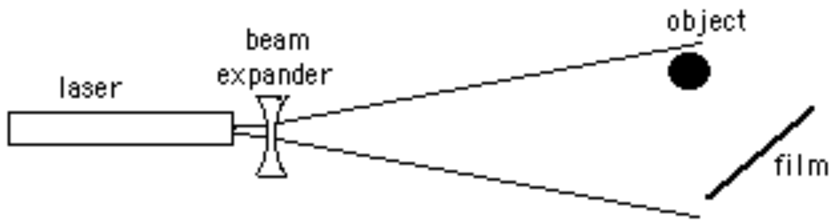

Fig. A: Schematic optical set-up

Although holography is in principle simple, there are many factors in the process that can ruin the hologram. Dirty optical elements obstruct the path of the light and produce spurious interference fringes, so it essential to make sure that all the elements are clean before use. Very high resolution film is needed to record the fine detail of the interference fringes which contains the information stored in the hologram. Such film is very slow, and correct exposure is essential. Because the information is stored on such a fine (sub-micron) scale, the biggest problem is vibration; even the slightest movement in any part of the setup during exposure can obliterate the hologram. The procedure below suggests ways of minimizing vibration generated within the lab, but even vibrations travelling though the building can sometines cause trouble.

In this lab, there are some pieces to the set-up which may be new to you. Familiarize yourself with them while the lights are on, so that you can find them in the dark. Everything except the film development is done on an optical table—a table engineered to reduce transfer of vibrations from the floor to the optical elements.

In the film prep area at the right end of the optical table, you will clean the glass plates, cut the film, and position it in between the glass plates for exposure.

Next, you will work at the film exposure set-up sketched in Fig. A. All of the elements can be attached the optical table in the same fashion as when you built a laser. In the resulting setup, coherent, monochromatic light originates in the laser and travels through a beam spreader. After leaving the beam spreader (in this case, a series of 3 lenses), the laser beam has been expanded to a greater diameter, so that (during an exposure) all of the film and the object will be illuminated. The light can be blocked close to the laser by a piece of black cardboard that is held up by a clamp. About a meter from the beam spreader there are two posts with screw threads on their ends that match those on the optical table. The film is sandwiched between two pieces of glass; this sandwich stands vertically on the table, firmly clipped to the two posts that are attached to the table. The glass / film sandwich will be held together using two additional clips. The object will be placed in front of the film setup but to the side, where it will also be firmly anchored.

The remaining part of the setup is the film developing area, on a table to the right of the optical table. To reduce the risk of spills, all this work is done in a large tray. Here there will be two small trays with tongs, one for the developing chemical and one for the fixer, a pitcher of water with a faucet and drain for rinse, with tongs, a piece of glass with a photographic squeegee, and a stand with clips for drying the hologram.

Apparatus:

1 10 mW 632.8 nm He-Ne laser
1 optical table or breadboard
1 ball driver
5 bases
5 post holders
5 posts
3 lens holders
1 25 mm double concave lens (f = 25.0 mm)
1 25 mm plano concave lens (f = 25.0 mm)
1 25 mm double convex lens (f = 25.0 mm)
1 laser tube mount
Screws and washers to attach elements to table
3 posts with $\frac{1}{4}$ /20 screw ends to attach glass to table
2 glass plates to hold film
binder clips or clamps for glass plate
non-AH film
black cardboard or foam-core board
stand to hold shutter
1 lamp with green filter and bulb
black cloth to cover breadboard
2 wood (or plastic) blocks to press film between plates
1 pair scissors to cut film
2 plastic dishes for developing
3 pairs of tongs
film developer (Dektol) and fixer
water
waste bucket and funnel
1 stand with clips for drying
1 piece of glass for squeegee
1 squeegee
paper towels
1 die and other objects for subjects
red sticky wax
black base for subjects
glass cleaner
lens cleaning wipes
blower for lens cleaning
kimwipes
watch / timer
individual flashlights with green filters
laser safety glasses
rubber gloves
general chemical splash goggles
sample hologram of die

Procedure:

You must read and be familiar with all of the procedure ahead of time because most of this lab is done in near total darkness. Also, relatively high powered lasers will be used for this lab, so you should wear safety glasses and take care to keep your head out of the plane of the laser so that your eyes cannot be damaged.

1. Laser mounting (this may already have been done). With washers on the screws, loosely screw two bases and post holders to the far right side of the breadboard, so that the post holders are aligned with a row of screw holes. <u>Place one of the longer screws in the laser mount, and drop it through the left or right of the three holes, so that the bottom barely reaches through the bottom of the mount.</u> You can now turn a post upside down (where there will be a larger screw hole) and attach it to the screw you have inserted through the laser mount. Do the same to attach a post to the hole in the opposite end of the laser mount. Tighten this assembly. Place the posts in the post holders that you have fastened to the table. You may need to move the bases some so that the posts will fit into the post holders (see Figure 4). With the posts of the laser mount completely seated in the bases, tighten the thumbscrews to secure the height of the laser. Place the laser head in the mount so that it is

centered, and tighten the screw on the mount to secure the laser. Adjust the position of the bases so that the beam will fall directly over one row of screw holes, along which you will attach the beam spreader assembly.

2. Make the beam expander. Unlike the one you made inthe physical optics lab, this one produces a divergent beam (see Fig. A on p.2) Mount two 25mm DCV in one holder and a 25 mm DCX lens in another **These lenses are very sensitive to dust and scratches. Take great care not to touch the surfaces because they are easily damaged. PUT ON YOUR LASER SAFETY GLASSES**. This laser is powerful enough to damage your eyes, so especially during this alignment process you will want to take care to protect your eyes in case a stray beam comes your way. Remove all watches and jewelry, so that the possibility of reflections is minimized. Use the key on the front to turn the laser on. Note the time, because you will later need to make sure that the laser has adequately warmed up. Place the pair of concave lenses centrally in the beam about 10 cm from the laser, and the convex lens at a further 25 cm so that the beam just fills it (se fig. 7).

3. At about 1 m from the beam expander the beam will be a large circle, in which you will want all of the parts shown in Figure A centered. So, look at your table to gauge how you should set this up. As far away from the laser as possible, screw the posts into the table so that the filmholder will be at about 45^{o} to the beam (see fig. 9). Note that this is only a suggestion, and you are welcome to try changing this angle later in the exercise when troubleshooting or otherwise intentionally changing the setup. Also, loosely secure the base for the object to the table and attach the object (a die for the first hologram) to the base using red sticky wax. The position of this base is to some extent arbitrary, and you will probably change it later, but make sure that scattered light from the object can reach the film, and that the OPD between the reference and scattered beams is not more than about 10 cm.

4. You will want to dim the lights by turning some off, though total darkness is not necessary for this step. Adjust the beam spreader to center the beam; remember, not only that you can adjust the height, but also that the loose screws in the base should make it moveable in the direction perpendicular to the beam. To help in centering the beam, place a piece of foam core board behind the object/film setup to see where the entire beam is falling. The illumination of the board in the region of the beam that strikes the film and the object should be as uniform as possible. Keep a sharp lookout for circular interference fringes which come from specks of dirt on the beam expander lenses .If you see these fringes, remove each lens, starting with the one furthest from the laser, carefully clean it, blowing off any lint remaining on the surface, and replace it, until no fringes can be seen. When the beam is centered, tighten the thumbscrews and screws on the bases to firmly anchor them. The enlarged laser beam is unlikely to damage your eyes. **However, you should keep your safety glasses on to minimize the risk, since there may be stray reflections. If you notice a stray reflection, block it with an opaque object**. Hold or clip the glass up to the post, as shown in Figure 6. Now, you will want to look though the glass (toward the laser) as much as possible without looking directly into the laser. Look at the way your object is illuminated from the perspective of the glass (and, eventually hologram). Adjust the setup so that the orientation of the object provides a desirable perspective on it, and as much of the object as possible is **directly** illuminated by the laser; the angle of the glass to the object should allow a

clear view of most of the object by direct light. Be careful that you do not mistake light reflected by the glass onto the object as light coming directly to the object from the laser, because this reflected light will NOT add to the hologram; to check this, temporarily shade the object from this reflected light. When you have made the setup as you wish, make sure everything is tightened down to prevent vibrations being transferred from air currents. You may turn the lights back on. Before exposing film, the laser will need to have warmed up for approximately 15 minutes. During this time, steps 5 through 9 may be completed.

5. Use the piece of black cloth and small pieces of black foam core board to cover the top of the table surface in between the laser and the film/object setup. You will be unable to cover the entire table, but cover as much as possible. (The problem with an uncovered table is that usually the hologram that results is of the table, rather than of the object. Thus, blacking out as much of the table as possible will minimize this risk.)

6. Close to the beam spreader place the stand which will hold the black cardboard in front of the beam; this board will block the beam while you are positioning the rest of the setup. The holder should be positioned such that it does not cast a shadow on the film / object setup. Put the board in the holder. Put out the lights and check that reflections from this board do not illuminate the walls or any other lightly colored area - if necessary cover any such illuminated areas with black cloth.

7. You will now prepare the 2 glass plates that will be used to sandwich the film. Hold each carefully by its edges to avoid smudging the glass, and clean both sides of each plate with the glass cleaner and paper towels. It is VERY IMPORTANT that the glass be totally clean to get a good hologram. Set the clean plates on the table so that the bottom edges of the plates extend a little beyond the edge of the table; mentally note where you have placed them—you will have to be able to find them in the dark and pick them up without dirtying them.

8. Note the placement of all the materials in the lab that you will be using, including everything needed through the developing stage. Be sure that you have finished the above steps and have properly prepared the apparatus because once the lights are shut off, they cannot be turned on until the film has been developed nd fixed.

9. Turn off all of the lights in the room except the laser, which should now be blocked with the cardboard. Wait approximately 3 minutes for your eyes to adjust to the total darkness. During this adjustment time, look around the room and try to spot any significant laser beam reflections. If you do detect a reflection of the beam "floating" somewhere, and cannot block itwith black cloth, you may have to adjust the laser and/or beam spreader after the green light is turned on. These adjustments must leave the center of the spread beam falling on the object, but eliminate the "stray" beams; you should follow any adjustments you make by verifying that the object is still sufficiently illuminated. Giving your eyes time to adjust in the total darkness before turning on the green lamp is VERY IMPORTANT; if you don't take adequate time now, your eyes will adjust much slower and the next parts of the lab will take longer and be more difficult!! Once you feel that your eyes have completely adjusted to the darkness, turn on the green lamp—even though the lamp may have seemed very dim

when the lights were on, you should now be able to see very well by the light that it provides.

10. Trying not to expose the film directly to any light (including any direct green light from the lamp), you should carefully remove it from the protective envelope and use the scissors to cut one piece that is approximately 3 inches long, if it has not alrady been cut. Return the unused roll of film to the carton, making sure that you adequately seal the carton with black tape so that no light will penetrate. Take the piece of film and place it on top of one of the prepared glass plates, taking care not to smudge the glass, so that the emulsion side of the film is facing up (the emulsion side is stickier when lightly touched on the corner with a moist finger). Place the other glass plate on top of the film and clamp this "sandwich" together using the 2 clips. With the emulsion side up, place one of these clips on the top side, toward the right corner of the sandwich and the other on the left side, in the middle (see Figure 8). Though the picture gives the basic idea, you should make two small changes. First, the clip on the top should be put on the very edge of the glass, because one of the posts on the table will go *through* the middle of the clip. Second, the clip on the left side should actually be more toward the middle, rather than at the bottom; the exact placement, however, is not crucial because this clip simply maintains the pressure on the glass.

11. Set one wood (or plastic) block on the tabletop and place the sandwich on top of it (again, emulsion side up); place the other block on top of the sandwich—you will have to position the glass so that the clips are hanging out of the sandwich. Now press very hard on the top block, and continue pressing for 15 seconds to eliminate all air bubbles from inside the glass plates.

12. Remove the sandwich from between the blocks and position it on the table so that the clip that was on the "top" in Figure 8 has the post closest to the object (the one at top of Figure 6) going through it (see Figure 9). The emulsion side of the film should be facing the object to be recorded. A roll of duct tape makes a convenient support for the plate. If the clip doesn't easily slide down the post, you'll need to gently work the clip toward the edge of the glass to free up more space; if the clip accidentally comes off, simply return to the film prep area, re-press the glass, and reposition the clips. Use another, large binder clip to clip the sandwich to the second post by opening it fully and putting it around both the glass and post. The setup should be firmly anchored now.

13. Hold a small piece of cardboard in front of the laser **(without touching the laser)** so that it blocks the laser beam. Remove the clamped cardboard and set it aside while continuing to hold the other piece in front of the beam. The piece you are now holding will act as the shutter, blocking the light except for the short film exposure time.

14. As explained in the introduction, ANY vibrations of the table or the air during the exposure will destroy the hologram. Make sure that no part of your body is touching the table and remain SILENT and COMPLETELY STILL for 15-30 seconds, then quickly but smoothly lift the cardboard up and allow the laser light to illuminate the object. Expose the film for about 1 sec), then quickly bring the cardboard back down to block the light. Keep holding that piece of cardboard in the beam until the other one can be replaced in the clamp. After

being certain the cardboard is clamped in front of the beam, you may now set down the cardboard that was being held, allowing the beam to fall on the clamped one.

15. Unclip and remove the sandwich from the posts, making sure that you avoid touching the glass. Carefully remove the clips holding the sandwich together (you don't want to leave fingerprints on the film, which will remain, or on the glass, which will be used in other exposures), and open the pieces of glass. Drop the film into the plastic dish containing the developer; for 2.5 minutes, gently rock the developer dish to move the film around in the chemical. (Note: the developer is very toxic, so make sure to wear safety gloves and wash your hands before coming in contact with food after the lab.)

16. After the 2.5 minutes, use the tongs for the developer to reach into the chemical and remove the film. Rinse it briefly and immediately place the film in the tray containing the fixer. As with the developer, rock the tray gently or push it around with the fixer tongs for about 3 minutes.

17. Finally, use the fixer tongs to remove the film from the fixer. Rinse it under the faucet for at least 5 minutes; after this rinse time, use a third pair of tongs to place the film on the large glass plate; leave a small portion of one corner hanging off the glass. The lights may now be turned on with no danger to the film. Use the squeegee and apply firm pressure to remove all excess water from the film. Use the overhanging corner to peel the film off the glass, and repeat the procedure for the other side. At this point, any water left on the film will dry there and leave watermarks on the surface. Attach one of the clips to the film, and then suspend that clip from the stand; allow the film to dry completely—about 15-20 minutes. When dry, the film will be dark gray (not solid black) and, when closely examined, will have a relatively uniform pattern (from the interference) recorded on it.

18. Before exposing the other pieces of film, you will want to find out if the procedure has left you with an acceptable hologram. When the film is COMPLETELY DRY, turn off the room lights (though perfect darkness is not necessary). You will be viewing the hologram by passing laser light from the beam spreader through the film to your eye; for this reason, you should be wearing the safety goggles while viewing the image. You should stand with the table setup, beam spreader, and laser in front of you. With the non-emulsion side of the film facing you, place the hologram in the light beam and lower your head close to the film. Without looking into the beam spreader / laser directly, look through the film. Move your head and the orientation of the film until you find the image. It may take quite a bit of movement before you discover the holographic image. Holding the film at the same angle of exposure sometimes helps to view the image, since you then know the approximate direction to look for the image. The image will be red in color and should appear "inside" the film. Once you find the image, slowly move your head in all directions and note how the image changes. Replacing the film into the table setup where it was produced may help in finding the image since this is exactly how the image was produced; however, you should first remove the object before viewing in this manner—it is easy to mistake the hologram for the object and vice-versa.

19. If you find a hologram in this exposure, move to the next step. Otherwise, you will need to repeat the procedure above to try to obtain your first holographic image. Before doing so, you should analyze your procedure and setup to try to find any problems that may have caused the hologram not to be created. Consider things like: Did you bump the table, touch the apparatus, move, speak or do something else to introduce a vibration? Are any of the pieces of glass or optical elements possibly dirty (you might notice odd ring patterns on the exposure if this is the case)? Was the film possibly exposed or developed for too long (i.e. is the film completely black—overexposure) or for too short (nearly white—underexposure)? if the former, try attentuating or spreading out the laser beam rather than shortening the exposure, since it is difficult with this set-up to control short exposures accurately. There is a rotary attenuator in the main lab; be careful to block the reflection from it. Was the angle and illumination of the object adequate? Did you touch the film other than on its edges? Whatever you decide was the problem, it should be changed in your next attempt and recorded in your lab notebook. You should return to step 7 and repeat the procedure, making any changes that you think might increase the likelihood of success. You should continue repeating this procedure until you successfully create a hologram in this manner, or until the end of the lab period, whichever comes first.

20. With a successful hologram created, you will now make more holograms after changing different parts of the procedure to see the effects on the hologram. First, you should remove the die and replace it with another object; in particular, you might want to try something less bright or more shiny (perhaps jewelry or a key). Different object characteristics simply produce different grades of results, but you will have to experiment to find out what these trends are. Now, return to step 7 and repeat the procedure to make another hologram. If time allows, you should then change the setup again to see the effect on the image; this time, use one of the objects you have already made a hologram of, but move the object closer to or farther from the film in the setup. Make a hologram with the object in this position by returning to step 8 and repeating the procedure.

21. After completing these three holograms, you are free to continue varying the setup and making holograms for the remainder of the lab period. See the "things to predict/test" question in the analysis section for other setup variations that you might want to try; also, feel free to test any questions or curiosities that you have regarding the process. Be sure to record in your lab notebook all changes made and observations of the holograms. When finished creating holograms, proceed to the next step.

22. Turn off the laser and the green lamp. Detach and disassemble the components on the optical table. Properly dispose of the developer and water. Rinse the plastic tongs and dish well to remove the developer residue. Wipe up spilled water and developer in the developing and squeegee area. Return all supplies to where you found them.

Analysis:

1. Judge the success of your attempt to create a hologram and discuss its features. You should also include things like
    - Is the image clear or blurry? Would you expect that a blurry image *could* be created? Why or why not?
    - What is the relative size of the image compared with the actual object?
    - Does the image seem to go into or come out of the page? Describe the degree to which the image has depth and is three-dimensional.
    - Approximate the greatest angle with the film (from perpendicular) through which you can turn your head and still view the image.
2. If your hologram did not work, describe the possible sources of error. If it did work, list some potential problems that could have caused difficulties or destroyed the image.
3. Things to predict and (if time) test. Explain your reasoning.
    - What would happen to the hologram if you moved the object closer to or farther from the film?
    - If you used a duller, more matt-finished object?
    - If you exposed the film for much more or much less time, what other change, if any, would you need to make to create a successful hologram?
    - What might happen if you didn't press the glass/film sandwich with the blocks of wood? How would that affect the hologram?
4. Hypothetical Discussions. Explain your reasoning.
    - In class you have learned about linear polarizers. How might the image, its properties, or the procedure change if you inserted a polarizer between the laser and the beam spreader?
    - How would moving the beam spreader forward or backward change the holographic results?
    - What do you think would happen if you used a green laser instead of the red one?
    - What would happen if any of the optical elements were dirty? (hint: think of what would happen when the light would encounter the dirt)
    - Why is it important for the center of the laser beam to be placed on the object? (hint: the effects of this phenomena may have been evident on the edges of your film)
5. Discuss the technique you used to view the hologram. Did you have to bend, rotate, etc. the film to see the image? Where was the light source in relation to the film?
6. You were told that any motion in the setup would cause the hologram to be destroyed. In two or three sentences, explain why this occurs (hint: think about the definition of a hologram).
7. What do you think would happen to the image if you cut the film in half? Into four pieces? (make sure to mention how it will be different from an image that was not cut) (hint: visualize looking through the hologram, as a "window" between you and the object).

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