Holography

Information document on the fabrication of holograms

This document contains a short description of the fabrication process of holograms. It will describe in detail the construction of the recording setup, how to create actual holograms, as well as explain the physical principles underlying holography.
The holography principle

Holography is a three-dimensional photography technique that relies on the properties of coherent light emitted from lasers. The word holography originates from the Greek *holos* (entirely) and *graphein* (to write) and therefore means “to display entirely”. To create a hologram, one needs to shine a coherent light on an object and record the interference fringes resulting from the combination of the wave emitted by the laser source (reference beam) as well as the wave reflected by the object (object beam) on photosensitive film. This is different from traditional photography that only records light intensity as holography also captures the light phase, thus capturing the depth positioning of the object.

The fabrication of holograms can essentially be divided into two steps: recording and development. Recording involves the superposition of the reference laser beam and the object reflected beam on a holographic film, which is a film on which an emulsion of silver halides has been deposited. The superposition of laser beams generates an interference pattern which results in alternately light and dark zones caused by the constructive and destructive interference phenomena. On the holographic film, this intensity modulation cannot be seen with the naked eye since it is on such a tiny scale that it is measured in micrometers (about a hundred times smaller than a human hair). The holographic film is reactive to the laser light in such a way that its chemical structure is modified in the constructive interference zones and left unchanged in the destructive interference zones. The hologram can be regarded as a complex diffraction grating. During the development step, the pattern of this diffraction grating is revealed. In the bleaching bath step, the silver atoms present in the photosensitive emulsion are either transformed into translucent halides or removed entirely. This creates a refractive index modulation or a thickness modulation in the resultant hologram which, when lighted properly, will reproduce the object.

Two types of holograms exist: the first type is reflection holograms which can be observed using a white light source like sunlight or a lamp. The second type is transmission holograms which can only be revealed using coherent monochromatic light (laser light). The difference between these two types is in the recording process (figure 1). In the reflection hologram case, the reference beam and the object beam reach the holographic film from both sides; the interference fringes produced are thus parallel to the film. For the transmission hologram, the reference beam and the object beam reach the holographic film on the same side; the interference fringes created are therefore perpendicular to the film.

Holograms are used in a wide variety of areas. They are used in museums to create replicas of rare and fragile items. Many artists, with Salvador Dali as a precursor, have integrated holography into their creations. Holograms are also used as a protective measure against counterfeiting credit cards, bank notes and passports. Interferometry is another field where holography shines, bringing an extreme precision to the inspection of micro-deformations on objects. Hologram interferometry makes it possible to observe streaks on the deformed parts corresponding to distance variations of a half-wavelength or a few hundred nanometers ($10^{-7}$m).
Figure 1: Reflection hologram recording setup and transmission hologram recording setup
Necessary material

Recording setup

The recording setup to create the holograms was mounted on an optical table supported on vibration isolation legs. The recording can be done using a low power laser (around 1mW), but that would require a longer recording time which would allow for larger detrimental effects from the vibrations. When choosing the laser, it is important to verify that the coherence length is long enough (ideally around 1 meter). The opto-mechanical pieces were mainly bought from Thorlabs. We have created a mount that closes magnetically (see figure 4) in order to hold the holographic film between the two glass plates flat.

<table>
<thead>
<tr>
<th>Qty</th>
<th>Description &amp; part number</th>
<th>Supplier</th>
<th>Cost</th>
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<tr>
<td>1</td>
<td>HeNe Laser, 632.8 nm, 35 mW, Polarized, 115V (HRP350)</td>
<td>Thorlabs</td>
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<td>2</td>
<td>Ø1&quot; 50:50 UVFS Plate Beamsplitter, Coating: 400 - 700 nm, t = 5 mm (BSW10)</td>
<td>Thorlabs</td>
<td>102$</td>
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<td>1</td>
<td>Three-Axis Spatial Filter (900)</td>
<td>Newport</td>
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<td>Valumax Objective Lens, 40x, 0.65 NA, 4.4 mm Focal Length (MV-40X)</td>
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<td>Edmund Optics</td>
<td>28$</td>
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<td>8</td>
<td>Kinematic Mount for Ø1&quot; Optics with Visible Laser Quality Mirror (KM100-E02)</td>
<td>Thorlabs</td>
<td>105$</td>
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Michelson interferometer setup

As an introduction to the interference concept, we have built a Michelson interferometer. We deviate the helium-neon laser beam towards the interferometer setup using a mirror which can be placed on a flip mount.

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<td>Thorlabs</td>
<td>102$</td>
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<td>3</td>
<td>Kinematic Mount for Ø1&quot; Optics with Visible Laser Quality Mirror (KM100-E02)</td>
<td>Thorlabs</td>
<td>105$</td>
</tr>
</tbody>
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Development

To prepare the solutions for development, adequate glassware is necessary (beaker, graduate cylinder, Erlenmeyer). We also need a magnetic agitator, a magnetic heating plate, a thermometer and storing containers. To prepare the different solutions, we use a magnetic agitator and the heater plate (see the section Development solutions preparation). For the development step, the solutions are placed in identified plastic containers. The holographic films and the development kits were bought from the Integraf company. These films need to be stored in a dark place, which is why we keep them in the black envelopes provided by the supplier.

<table>
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<th>Supplier</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>1</td>
<td>JD-2 Holography Processing Kit</td>
<td>Integraf</td>
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</table>
Setup

Recording setup

The holography setup is shown in figure 2. The object from which we want to create a hologram is lighted from 3 beams: a central reference beam and 2 lateral beams. The setup has been designed so that the three beams travel along paths of equivalent lengths. What is important is to make sure that the difference between the optical path lengths is shorter than the laser coherence length. We have previously evaluated the laser coherence length by observing the interference figure produced by a Michelson interferometer by changing the optical path length difference between the two interferometer arms. We have noted that the interference fringe visibility was seriously compromised for optical path length differences longer than 20 cm.

The central beam is filtered by making use of a three-axis spatial filter that consists of a mount with a lens and a pinhole whose position can be adjusted along the three-axis. The central beam is widened by means of a 20X lens placed one meter away from the film to permit an even lighting. The lateral beams are equally widened using objectives, and we have used 40X lens positioned 49 cm away from the film. We have placed beam-stoppers on each side of the holographic film to prevent the lateral beams from shining directly on it.

For certain objects, lighting from a single arm is adequate. In those cases, the beamsplitters can be replaced with mirrors so that the whole laser power is in the central arm. This also minimizes recording time.

![Diagram of holographic setup](image)

**Figure 2**: Setup for hologram recording

Before recording a film, alignment of the spatial filter (figure 3) has to be verified. If the setup has not changed since the last use, the filter position should be close to optimal. Two verifications should be made:
1. Observe the filtered beam on a screen. Does the beam show the rings from the Airy pattern due to the pinhole beam diffraction? If it does, perform a fine adjustment of the pinhole position on both the horizontal and vertical axis (x-axis and y-axis) until the Airy pattern vanishes. If the rings are still visible, it is possible that the pinhole longitudinal position (z-axis) is not optimal. In this case, adjust the transverse positions (x-axis and y-axis) and the longitudinal position (z-axis) alternately until you get a clear beam. If the Airy pattern is still observable, it might be that the pinhole diameter is too small. This could be fixed by using a pinhole with a larger diameter.

2. Measure the filtered power to input power ratio. If the value of the ratio is approximately 90%, then the pinhole position is correct.

Figure 3: Three-axis spatial filter.

To realign the spatial filter, follow the procedure below thoroughly:

1. Place a target with concentric rings about ten centimeters behind where you plan on placing the spatial filter on the optical axis.

2. While keeping the lens position fixed, adjust the position of the spatial filter mount laterally and vertically so that the beam comes out of the lens and hits the target in its center. Also ensure that the laser beam passes through the lens with a normal incidence angle by looking at the beam reflection on the lens. Keep this spatial filter mount position fixed from now on.

3. Place the pinhole on the magnetic mount.

4. Using the z-axis adjuster, move the pinhole to a distance a few millimeters larger than the working distance of the lens.

5. Place a detector as close behind the pinhole as possible.

6. Using the x- and y-axis adjusters, optimize the output power of the pinhole.

7. Gradually bring the pinhole close to the lens using the z-axis adjuster until the output power is maximized.

8. Repeat steps 6 and 7 until the output power is at least 90% of the input power.
9. Observe the transmitted beam on a screen. If diffraction rings are visible, make a small adjustment to the x and y positions of the pinhole until they disappear.
Hologram fabrication process

Hologram fabrication can essentially be divided into two steps: recording and development. Prior to the recording, it is necessary to inspect the setup and adjust the spatial filter alignment as described in the preceding section. The development solutions must also be prepared in advance.

Preparing the development solutions

The products used for the development are the JD-2 development kit from the Integraf company. It consists of a solution A (distilled water, catechol, ascorbic acid, sodium sulphite and urea), a solution B (distilled water and sodium carbonate) and a Bleach solution (distilled water, potassium dichromate and sodium bisulphate). The A, B and bleach solutions are prepared according to the Integraf company protocol available here: http://www.integraf.com/jd-2_holography_developer.htm. However, a more detailed protocol for the preparation of the solutions is presented below.

1. Measure 1 liter of water in a 1.5 L or 2 L Erlenmeyer flask. Place it on the heater plate and insert the magnetic agitator and a thermometer.

2. Adjust the heater plate temperature and agitator prior to incorporating the chemicals into the flask. Monitor the thermometer so that the solution NEVER REACHES 100°C.

3. For solution A, start by dissolving the catechol because it is the most difficult to dissolve. DO NOT USE A METALLIC ROD TO HASTEN THE DISSOLUTION. Once the catechol is dissolved, add the other products one at a time and make sure they are well-integrated before moving to the next one. For solution B and the Bleach, there is no precise order for the chemical dissolutions.

4. Repeat steps 1 through 3 for solution B and the Bleach but take care to rinse the Erlenmeyer (if you are using the same flask) well between each solution using tap water. The contaminated water should be discarded in the disposal container for chemical products.

5. Once the solutions are mixed, place each solution in opaque plastic containers. Put the containers away in a secure, well-ventilated and clean location inside the exposure and development laboratory. However, solution A and the Bleach must not be in the same storage space since the former is a reducing agent and the latter contains oxidizing agents. When mixed together, this could create a small explosion!

The mixing of chemicals must take place in a proper chemistry laboratory under a hood and the scientist must wear a laboratory coat and nitrile gloves. All the security rules of such a laboratory must be followed. For more information, see Annex A: Chemical security summary.

Here is the solution mixing process for the solutions which will be placed in different containers pertaining to each development step:
1. Measure 100 mL of solution A using a 250 mL graduated cylinder and pour that into the container identified as “A+B”. Repeat with 100 mL of solution B. This is the developer solution.

2. Pour 1L of distilled or demineralized water into each rinsed water container. The level of water required is marked by a black line.

3. Measure 150 mL of the Bleach solution and pour it into the container marked “Bleach”. Use a dedicated graduated cylinder for the Bleach, and it should be identified and different from the one used for solutions A and B.

4. Prepare the wetting solution by measuring 5 mL of Kodak Photo-Flo and combining it with 1 L of water into the last container.

**Hologram recording**

Reducing vibrations is crucial for the exposure step. Therefore, if at all possible, use an optical table with active isolator leg bundles. Avoid having non-essential people in the room. During the recording, do not move or talk.

**Hologram recording process:**

1. Turn the laser security warning light (and/or any other security device) on.
2. Turn the laser on. Wait 30 minutes for it to stabilize.
3. Put on nitrile gloves.
4. Clean the glass plates used to hold the hologram. If they are only slightly dirty, use a lint-free cleaning wipe and isopropyl alcohol. If they are filthy, clean them in soapy water first, then rinse them in distilled water and finish the washing with isopropyl alcohol. The glass plates used here have an anti-reflection coating at 633 nm which eliminates parasitic reflections that could otherwise interfere with the holographic film during the exposure.

5. Turn off the regular lights and turn on the special green lights (or another light source that has no effect on holographic film).

6. Take the holographic film out of its container.

7. Put the holographic film in the support, in between the two glass plates, taking care to place the convex side (emulsion side) towards the glass pane identified “object” (figure 4). Make sure that the film is well-positioned in the support and that the support closes correctly by inspecting the side joints. If the film is larger than 10 cm x 10 cm, the support will not close correctly. In that case, slice the film again to meet the proper dimensions.

*Figure 4:* Film positioning in the mount.
8. Place the mount on the optical table. The "object" side must be placed towards the object.

9. Position the target object as close as possible to the holographic film.

10. Put the black Coroplast panes on the table so as to block parasitic reflections.

11. Adjust the electronic shutter exposure time to about 1 second with a few seconds of delay.

12. Be silent and unmoving while you activate the shutter.

13. Once the exposure is completed, take the holographic film out of the mount.

Hologram development

For the development step, the regular lights must be turned off, leaving only the special green lights on (or any other light source that has no effect on holographic film). Use nitrile gloves to protect the emulsion side of the film (convex side). Place the film with its convex side upwards during immersion in the solutions and use the tongs exclusively to move the film from one solution to the other. When doing this, take care to grab the film by one of its corners. Each development step is illustrated in figure 5.

1. Soak the hologram in the developer solution “A+B” for 90 seconds with its convex side upwards. Shake the container lightly to immerse the film completely. The film blackens because the silver particles in the film are darkening.

2. Place the hologram in the first rinsing basin for 90 seconds or longer for a more thorough rinse.

3. Soak the hologram in the Bleach solution for 90 seconds. The film becomes transparent due to the silver particles turning into translucent silver halides and dissolving into the solution. After this step, the regular lights can be turned on.

4. Place the hologram in the second rinsing basin for 90 seconds or longer for a more thorough rinse.

5. Soak the hologram 30 seconds in the wetting solution containing 5 mL of Kodak Photo-Flo and 1 L of water. The wetting solution accelerates drying and reduces the streaks. Using the tongs, take the hologram out of the wetting solution gently.

6. Dry vertically for 1 to 2 minutes.

7. Complete the drying using a hair dryer.
Hologram observation

Reflective holograms can be observed using a laser beam or white light. To see the hologram, you need to shed light on the same side that was exposed to the laser during recording, which is to say the back of the hologram. In order to see it better, it is best to place a support that maintains the film flat and to use a black background to increase contrast.

Reclaiming of chemicals

The developer solution is inert after 24 hours and should be reclaimed by placing it in 10 L reclamation containers. The A+B solution, the bleach, the rinsing water and the Photo-flo should all be stored in the recycling container for “used developer” solutions. The empty containers and the “used developer” stickers used to identify them can be obtained from the 0351B office. The maximum quantity of liquid in the containers must not be over 10 L or the chemical reclamation service will not pick them up. When the containers are full, they should be brought back to the 0351B office using the chemical reclamation pushcart found there. Finally, you need to fill-out an electronic form located here: [http://www.ssp.ulaval.ca/matieres-dangereuses/risques-chimiques/cueillette-des-produits-chimiques/](http://www.ssp.ulaval.ca/matieres-dangereuses/risques-chimiques/cueillette-des-produits-chimiques/)
Recommended demonstrations

As an introduction to holography for students, it is recommended to start by telling them about lasers: what are the characteristics of laser light, and how does a laser work? Moreover, since the hologram fabrication process is based on the interference of two laser beams, a Michelson interferometer setup can be useful to illustrate an interference pattern.

Laser operating principle

The word laser is actually an acronym for “Light Amplification by Stimulated Emission of Radiation”. The laser effect creates a type of light nearly inexistent in nature. This light has a single color (monochromatic), appears in a tightly focused beam (directional) and all its component photons are identical (coherent). To reveal the inner mechanisms of a laser, we use a helium-neon laser with a Plexiglas container (figure 6).

![helium-neon laser](image)

**Figure 6:** helium-neon laser.

- To create a laser you need a gain medium (in the figure above it is a Helium and Neon gas mix) which has electrons in an excited energy state brought about using an energy source (also called pumping system). In this case the pump is an electrical power source.
- Once the electrons are in an excited state, they get back naturally to their lowest energy state by randomly emitting a photon. You can show the He-Ne spontaneous emission light which is purple.
- An optical cavity can be created using mirrors which forces the light to travel back and forth. These photons stimulate the emission of more photons which have the same characteristics (direction, wavelength and coherence). This chain reaction amplifies light emission.
- One of the mirrors from the cavity leaks between 1 % and 5 % of the light. The photons coming out of this cavity are all identical in direction, waveform and color. Figure 7 depicts the laser operating principle.
There exists many kinds of lasers classified by their gain medium: solid-state lasers, gas lasers, semiconductor lasers or dye lasers. The laser used for holography is also a helium-neon laser, albeit a much more powerful one than the demonstration laser.

**Interference phenomenon**

What happens when two laser beams are superposed? Does the light simply get more intense? The reality of it is that alternating light and darkness zones known as an interference pattern appear.

To better illustrate this phenomenon, we will use the Michelson interferometer setup shown in figure 8. Let us describe the laser paths in this setup. A beamsplitter divides an incident beam into two by reflecting half of it and letting the other half pass through. Mirrors placed at the ends of the two optical arms (of similar lengths) send these two beams back towards the same beamsplitter which recombines them together. A lens is used to enlarge the beam to display the interference pattern on a screen. Pressing on the table or lightly tapping it will aptly illustrate the effect of vibrations by temporarily blurring the interference pattern.

Hologram recording is based on the interference principle as applied to two superposed beams. The holographic film records the interference fringes generated by the superposition of the incoming beam (reference beam) and the beam reflected on the object (object beam). During the recording process, it is crucial to minimize vibration sources that could blur the interference fringes. That is why short recording times are favored.
To align the Michelson interferometer setup:

1. Close the pinhole to block the beam.
2. Add a mirror right in front of the three-axis spatial filter so as to deviate the beam towards the interferometer (figure 9).
3. Open the pinhole.
4. Adjust the mirror inclination so that the reflections are reflected back through the pinhole.
5. Interference fringes should be visible on the screen.
6. Varying the XZ and YZ planes adjustment screws on the mirrors will change the length and orientation of the interference fringes.

*Figure 8: Michelson interferometer.*
Figure 9: Aligning the Michelson interferometer.
Annex A: Chemical security summary

1. Wear a LAB COAT, SECURITY GLASSES and GLOVES at all times.
2. TIE YOUR HAIR at all times.
3. Wear LONG PANTS, SOCKS and CLOSED SHOES. No skin should show below the belt!
4. In case of CONTACT WITH THE EYES: If a chemical enters your eyes (or eye) you must take off your gloves, take out contact lenses (if necessary) and rinse abundantly with tap water for 15 minutes. Then, proceed to the EMERGENCY ROOM of a hospital!!!
5. In case of SKIN CONTACT: If a chemical touches your skin you must rinse the affected area abundantly with tap water for 15 minutes. Then, read the chemical safety data sheet to know if you should proceed to the EMERGENCY ROOM!
6. CHEMICAL DAMAGE: If you drop solid chemicals on the floor you must clean them up using a specially designated broom and take care to stir up as little chemical dust as possible. Place the product in a container and dispose of it appropriately.
7. WHEN LENDING ASSISTANCE: Do not forget to take off your own gloves (which are contaminated) and to put on new ones to prevent further contaminating the person you are helping.
8. NEVER PERFORM CHEMICAL PROCEDURES WHEN ALONE IN A LAB!
9. Always have the chemicals SAFETY DATA SHEETS for the products you are using at hand.