Optics

Wave optics
White-light Reflection Holography

LD Physics Leaflets

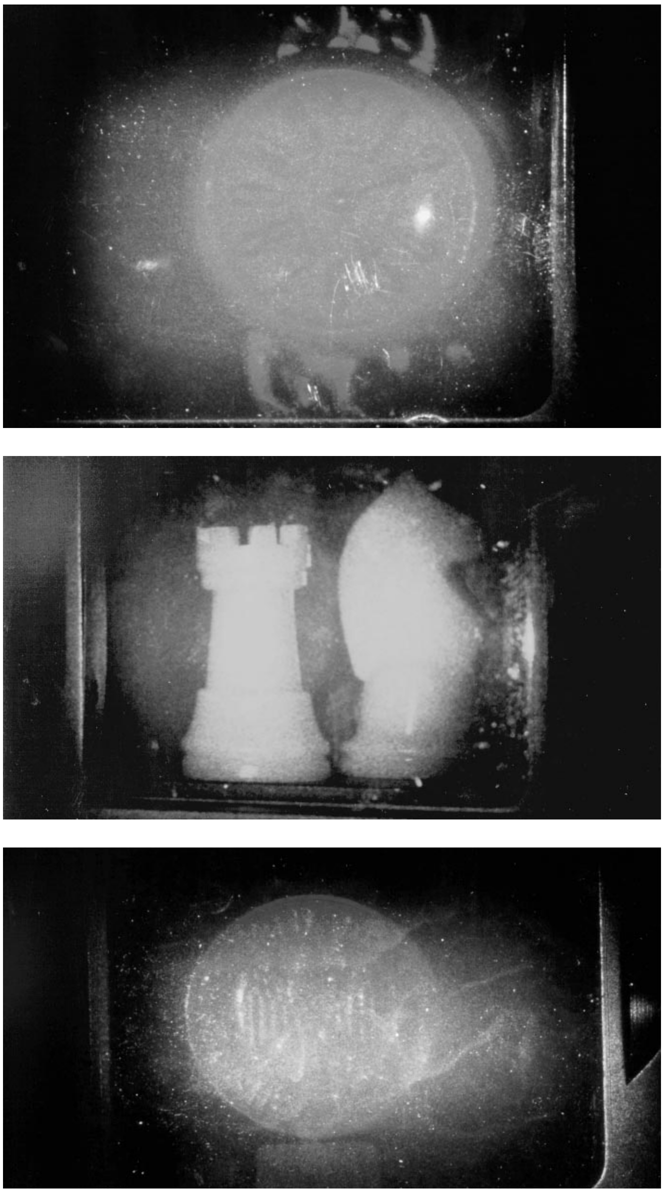
P5.3.6.1

Creating white-light reflection holograms on the laser optics base plate

Objects of the experiment

- Creating white-light reflection holograms
- Understanding the difference between amplitude and phase holograms and their photochemical processing
- Reconstruction of white-light reflection holograms

Fig. 1: Photos of holograms



Principles

In photography, the image of the object to be photographed is fixed on the film. In holography, on the other hand, the light waves reflected from the surface of the object are stored. The film records not only the amplitude of the wave radiation, but also its phase. As a result, the hologram can record the position of every point on the object in space.

There are several different types of holograms. Due to its simplicity, the setup for creating white-light reflection holograms is particularly suitable for those new to holography.

In *creating* a white-light reflection hologram, a widened laser beam passes through a recording medium (film) and falls on the object placed behind it. The light reflected by the irregular surface of the object is returned to the recording medium, where it is superimposed with the light waves of the original laser beam. Within this medium, interference results in the creation of standing waves, i.e. a series of planes of nodes and antinodes at a distance of $\lambda/4$ apart. The antinode planes are exposed, but the node planes are not exposed. The exposure is recorded in the form of semitransparent layers of metallic silver. The result is a three-dimensional diffraction grating which stores the information regarding the object in a sort of optical code.

In *reconstruction,* the light incident on the finished hologram is reflected by the semitransparent layers. This light has the same properties as light waves originally reflected by the object. Light beams emerging from different layers only reinforce each other when they are in phase. As a result, the hologram selects for a specific wavelength during reconstruction of the image. As the in-phase condition can only be fulfilled for a specific wavelength, it is possible to reconstruct the image with white light. Thus, a white-light reflection hologram has the property of being able to select the specific wavelength it requires out of a spectrum to reconstruct a three-dimensional image of the original object.

Depending on how the exposed film is photochemically treated, we can distinguish between two types of hologram:

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Apparatus

1 laser optics base plate	473 40
1 He-Ne laser, linearly polarized	471 840
1 laser support	473 41
3 optics bases	473 42
1 film holder	473 44
1 object holder	473 45
1 spherical lens, f = 2.7 mm	473 47
1 wooden ruler	311 03
1 Schuko socket strip	663 615
1 stopclock II	597 41
1 set of 6 small trays, 1×1 RE	649 11
3 polyethylene bottles, 1000 ml	661 234
1 scissors, 200 mm, pointed	667 016
1 holography film[1]	473 442
1 darkroom accessories	473 446
1 photographic chemicals[2]	473 444

For creating phase holograms:

Iron(III) nitrate nonahydrate, 250 g	671 891
Potassium bromide (KBr), 50 g	672 491

Additionally required:
For creating amplitude holograms:
1 drop washing-up liquid
1 absorbant surface, e. g. paper towel

Suitable:

[1] Agfa-Gevaert 2NFXQ HOLOFI 8E75 T3 HD NAH
[2] B/W paper developer Agfa Neutol,
fixer: Tetenal Superfix

Safety note

The He-Ne laser fulfills the German technical standard “Safety Requirements for Teaching and Training Equipment – Laser, DIN 58126, Part 6” for class 2 lasers. When the precautions described in the Instruction Sheet are observed, experimenting with the He-Ne laser is not dangerous.

- Never look into the direct or reflected laser beam.
- Do not exceed the glare limit (i.e. no observer should feel dazzled).

Some of the photographic chemicals are toxic and aggressive.

- Make sure you observe all the safety precautions given on the chemical packages.
- Wear protective goggles, protective gloves and a chemistry apron.

Used photographic chemicals pollute the environment. Do not pour them down the drain.

- Dispose of photographic chemicals as special waste.

An *amplitude hologram* consists of transparent and opaque sections caused by the silver grains formed in the development process.

In a *phase hologram,* the developed layer loses its opaqueness in a bleaching process. Depending on the specific bleaching process, the information is retained in the form of a change in the refractive index, thickness or ripples on the surface of the hologram. When the hologram is reconstructed, the light waves must travel different optical and geometric paths, so that optical path differences between the individual waves occur. We say that the hologram is phase-modulated.

As phase holograms do not absorb any of the light energy directed at them during reconstruction, they are significantly brighter than the optically dense amplitude holograms. This is why phase holograms are preferred for technical applications today.

Preliminary remarks

A certain amount of care is required in order to create good holograms. Ambient influences and incorrect handling can easily prevent creation of the hologram, or, at the very least, significantly reduce quality.

Ambient influences:

Among the most major disturbances are uncontrollable movements between the interference field and the recording medium. A change in the optical path length between the object and the film medium on the order of just $\lambda/4$ during holography is enough to completely destroy the hologram.

Such disturbances are caused, for example, by shocks to the setup, or by air streaking. In the following experiment, these influences are greatly attenuated, as the experiment is set up on the vibration-damping laser optics base plate. The base plate rests on a vibration-isolating air cushion, and has a cover to reduce convection.

In spite of the very good vibration isolation, ambient mechanical vibrations can still be transmitted to the experiment setup which are strong enough to affect the interference field during holography. These can be caused e. g. by slamming doors, feet stamping on the floor or a running machine. These influences must be eliminated.

Local changes in pressure and temperature also affect the interference field by significantly changing the refractive index of the air. Ventilation systems, drafts and nearby radiators are all negative influences. Their effects are even greater when these devices are just starting up. The experimenters themselves can also be the cause of air streaking. During holography, they should not stand or sit too close to the setup, and must never breathe on the setup. The same applies for all other persons present in the experiment room. You can reduce these influences greatly by using the cover.

You can easily detect the effects of mechanical shocks or air streaking using the Michelson interferometer, which can also be set up on the laser optics base plate (see ”Setting up a Michelson interferometer on the laser optics base plate”). The Michelson interferometer is more sensitive to such influences than the holography setup used here, as it shows movement in the interference pattern in response to these disturbances. For this reason, it is very useful for helping the experimenters to evaluate the ambient influences.

Selecting the object:

The object to be holographed must be sufficiently rigid; suitable materials include e. g. metals, hard plastics, wood, stone, etc. Soft materials, on the other hand, such as textiles, paper or even plants, are unsuitable, as they can easily move during holography.

Unsteadily standing objects should be secured using the retaining arm of the object holder so that they stand more steadily on the base plate. Toy cars often have spring suspensions; for these objects, the massive base plate of the object holder is provided with a narrow ridge, so that these cars can be arranged so that their wheels are off the surface.

It is only possible to obtain good white-light reflection holograms when using objects which are good reflectors of laser light. Dark objects should be sprayed with brighter colors or silver. The better these objects reflect the light onto the film, the more brighter the hologram will be. This is why coins, for example, produce very good results.

Handling the optical components

High-contrast interference phenomena can also be caused by dust particles, scratches or fingerprints on the spherical lenses and the variable beam divider due to improper handling. The light is diffracted at these faults, with the result that the hologram regions corresponding to the diffraction maxima are overexposed, and the regions corresponding to the diffraction minima are underexposed. This reduces the quality of the holograms. Thus, the spherical lens must be handled with great care and stored free of dust. Avoid damaging component surfaces or touching the components with your bare hands.

You can remove a soiled lens from its holder and polish it with a lint-free cloth are lens-cleaning paper. Be sure to read the respective Instruction Sheets!

Requirements for the experiment room

Experiments should be carried out in a room which can be sufficiently darkened, and which is free of shocks, as well as having a sufficiently even temperature. In addition, you also need a power source for the laser and the darkroom light, running water nearby for the final rinse and a sturdy bench or table which is not too high.

Preparation

Cutting the film material:

As the film is extremely insensitive at a wavelength of 505 nm, you can use a weak, dark-green (or blue-green) darkroom lamp as an orientation aid.
The film should not be illuminated directly.

Note which side is the coated side! The film is marked by a notch in the edge. If this notch is at the bottom right or top left, the coated side is facing away from you.

Handle the film carefully, so as not to damage the coating.

This film material consists of coated plastic sheets (sheet film) 10.2 cm x 12.7 cm, which must be cut to a suitable format.

– In complete darkness, remove the desired number of sheets and pack up the remaining film light-tight (storage in a cool place prolongs the shelf life of the film).
– Mark the points at which you wish to cut the film with a fine felt-tip pen and then use the scissors to cut the film into pieces 42 mm x 51 mm (tolerance 1 mm), see instruction sheet ”Equipment set Laser optics“.

Store the pieces you have cut to size in an absolutely light-tight container (note which side is coated!) and use them within one week.

Preparing the photographic chemicals:

– Clean the storage vessels (polyethylene bottles) thoroughly.
– Prepare the developer in one of the storage bottles according to the manufacturer’s instructions, and pour some of it into the appropriate plastic tray.

To create phase holograms:

– Make up a bleach bath of 100 g iron(III) nitrate nonahydrate, 30 g potassium bromide (KBr) in 1 l water (distilled if available) in the next storage bottle, and pour some of it into the appropriate plastic tray.

And/or for amplitude holograms:

– Prepare the fixer in one of the storage bottles according to the manufacturer’s instructions, and pour some of it into the appropriate plastic tray.
– Fill one tray with water (stop bath).
– Fill one tray with water and washing-up liquid (just one drop).
– Place one tray near running water for the final rinse.
– Label each tray according to its content.

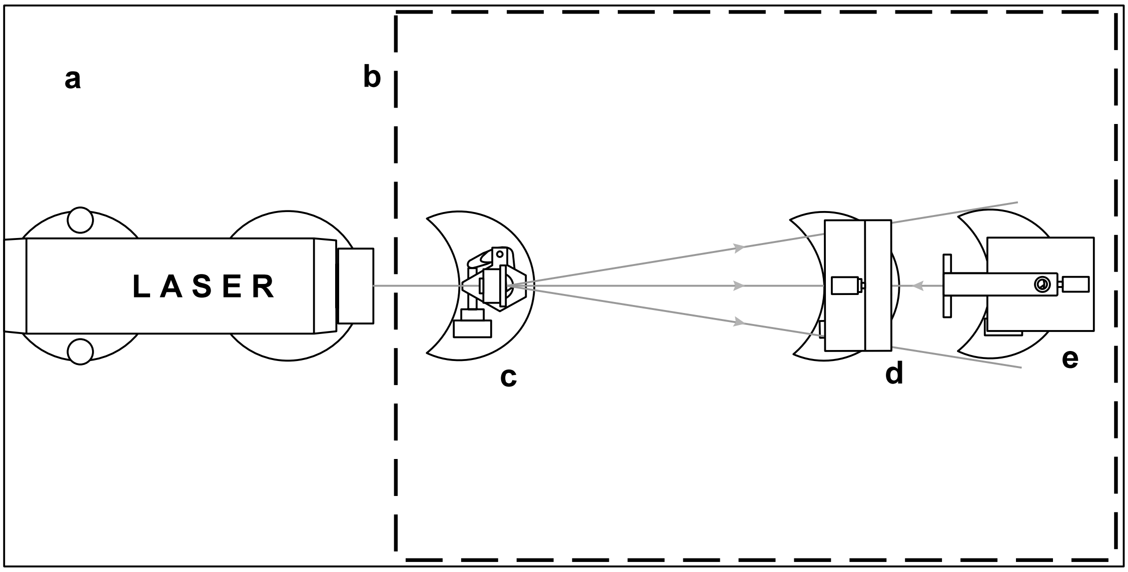

Fig. 2: Experiment setup for creating white-light reflection holograms on the laser optics base plate, top view
a laser optics base plate
b cover
c spherical lens
d film holder
e object holder

Setup

The arrangement of the optical components on the laser optics base plate is shown in Fig. 2. In setting up the experiment, carry out the following steps (make sure that all components are firmly seated in their holders!).

Laser optics base plate and laser:

– Pump up the air cushion.
– Attach the cover **(b)** to the laser optics base plate **(a)**.
– Place the laser optics base plate with air cushion horizontally on a sturdy laboratory bench.
– Mount the laser on the laser support.
– Place the laser as close as you can to the left edge of the base plate while still being able to close the cover with no problems.
– Connect the laser to the Schuko socket strip and switch it on.
– Loosen the three lock nuts of the adjusting screws on the laser support.
– Using the adjusting screws, adjust the height and inclination of the laser so that the beam travels perfectly horizontally about 75 mm above the base plate (there is still enough play for subsequent adjustment). Measure the spacing with the ruler.
– Tighten the lock nuts.

Film holder:

– Insert a piece of white paper cut to size in the film holder and place the film holder in the beam path about 25 – 30 cm from the laser as shown in Fig. 2, so that the beam strikes the center of the paper (and later, the film).

Spherical lens

Note:

You can vary the size of the area to be illuminated by the laser beam by changing the distance between the film holder and the spherical lens. A hologram can only form at those points at which the reference beam is incident on the film. Thus, the illuminated area should be at least as large as the object you wish to holograph. On the other hand, the exposure is more intense when the beam is only slightly widened. The exposure time can then be shortened, which makes the entire holography process less subject to local disturbances.

The quality of the widened beam is especially important for the quality of the hologram. Thus, the widened beam should be as free as possible from diffraction images, which can be caused by poor adjustment or by dirty or damaged surfaces on the lens or the beam divider.

– Place the spherical lens **(c)** between the laser and the film holder in order to widen the beam (the small opening of the lens holder must face toward the beam divider).
– Adjust the lateral position and the height of the spherical lens so that the laser beam passes through the lens as nearly axially as possible. Position the lens far enough away from the laser that you can still close the protective cover **(b)** (see Fig. 2).

Object holder:

– Remove the piece of paper from the film holder.
– If possible, secure the object in the object holder **(e)** using the retaining arm.
– Place the object holder as close as possible to the film, as shown in Fig. 2. Make sure that the object reflects a lot of light onto the film, the beam strikes the center of the object and the object is well illuminated.
– Make sure that you can still close the cover.
– Switch the laser to 1 mW power and check the quality and beam path of the widened beam. If necessary, readjust the lenses.

Carrying out the experiment

Inserting the film:

You can use a weak, dark-green (or blue-green) darkroom lamp as an orientation aid. However, the film should not be illuminated directly or up close.

– Switch off the laser. (In order to avoid shaking the experiment setup during exposure, switch off the voltage supply using the mains switch on the Schuko socket strip, and not the key switch on the laser.)
– Use your finger to steady the optics base with the film holder **(d)** and carefully remove the film holder from the experiment setup.
– Darken the room.
– Remove one piece of cut-to-size film from the light-tight film box. Handle the film only by the edges, so as not to damage the emulsion layer.
– Open the clamp of the film holder using the knurled screw.
– Insert the film sheet in the holder so that the coated side faces toward the object when you put the holder back in the experiment setup.
– Fasten the film neatly in the holder by closing the clamp.
– Use your finger to steady the optics base of the film holder again and put the film holder back in the experiment setup.
– Close the cover.

Exposure:

The optimum exposure time depends on the broadening of the laser beam, on the object and on the type of hologram, and must be determined empirically. For phase holograms at 1 mW laser power, a time of about 1 s to 3 s can be used as a rough approximation. The exposure time for amplitude holograms is about three to four times shorter.

The laser power limit of 0.2 mW is achieved using a gray filter, which reduces the quality of the hologram even further due to additional interference phenomena and increases the exposure time by approximately a factor of five.

– Wait about five minutes, to allow the film and tensions in the setup to settle.
– During the exposure time, do not do anything which could disturb the interference image on the surface of the film (see preliminary remarks).
– Expose the film by switching the laser on and off at the Schuko socket strip, without shaking the setup (e.g. by pulling on the power lead).
– Open the cover, remove the film holder from the experiment and remove the film by opening the clamp. Only handle the film by the edges.

Processing the film

When you have selected the correct exposure time, phase holograms appear dark gray after developing, and amplitude holograms appear light gray. Experienced holographers can vary the developing time somewhat in order to optimize the result. When using older or used developer, developing will take longer, as the agent becomes less active.

– Hold the film in one corner using the tweezers and agitate it in the developer for 60 s.
– Stop the development by agitating the film in the water bath (stop bath) for 2 minutes. The light-sensitive phase is now finished, and you can switch on normal lighting as necessary.
– To create a phase hologram, immerse the film in the bleach bath for approx. 5 minutes, but at least until no more black areas are visible, and occasionally agitate it, do not fix it.
– When making amplitude holograms, fix the film according to the manufacturer's instructions after development.
– As a final step, rinse under running water for 5 to 10 minutes.
– Briefly dip the film into the water with one drop of washing-up liquid; this prevents spots from forming when the film dries.
– Dry the hologram by standing it vertically or laying it on an absorbent pad.
– Clean the tweezers with water.

Evaluation

After drying, you can reconstruct the finished hologram with white light. The light must shine on the hologram from the same direction as it was originally exposed by the laser beam, and is also viewed from this side. The hologram has the sharpest focus when it is reconstructed with homogeneous light with the same divergence as the widened laser beam. Bright torches, halogen lamps, sunlight or even the widened laser beam are all suitable sources of reconstruction light. In reconstruction, the hologram shows reflection properties similar to the object itself when the light source is moved.

If you turn the hologram around so that it is illuminated from the "wrong" side, the object seems to be in front of the plane of the film (though less focused).

Additional information

Phase holograms are more light-sensitive than the fixed amplitude holograms, and fade more readily. Their light stability can be improved by means of a bath in a solution of 2.5 g potassium iodide (KI) in 1 l water. This process gives the holograms a slight yellow tone.

When making the hologram, the film does not have to be aligned perpendicularly to the laser beam. When the film is positioned at an angle, the viewer is not dazzled by the reflections of the light source on the film surface when reconstructing the image. The film can also be exposed more effectively over its entire width.

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