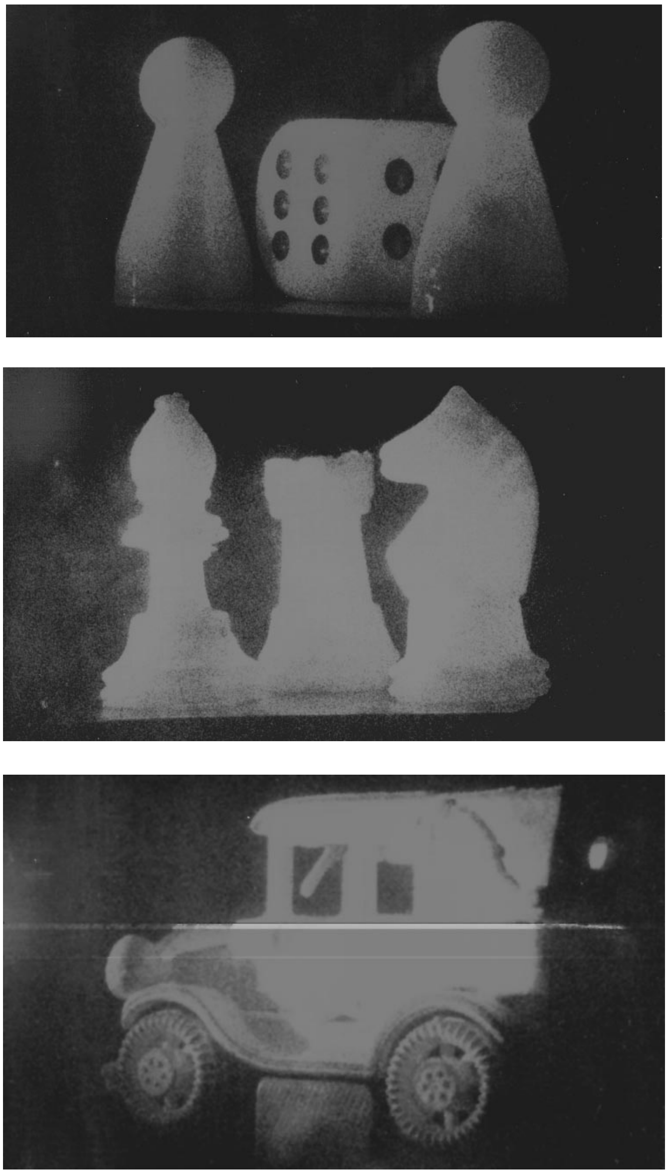
Creating transmission holograms on the laser optics base plate

Objects of the experiment

- Creating transmission holograms
- Understanding the difference between amplitude and phase holograms and their photochemical processing
- Reconstruction of transmission 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.

To *create a hologram,* a laser beam is split into an object beam and a reference beam, and then widened. The object beam illuminates the object. The light reflected from the object is channeled to a film, where it is coincident with the reference beam which is coherent with it and incident from a different angle. The resulting interference produces the hologram, an irregular pattern of dark patches, swirls and rings, which on the surface has no similarity to the object it is supposed to represent.

In *reconstructing the hologram,* a light beam corresponding to the reference beam is diffracted on the microscopically small interference pattern in such a way that the diffracted waves are practically identical to the waves originally reflected from the object. Thus, the observer can view a three-dimensional image.

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

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.

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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
5 optics bases	473 42
1 variable beam divider	473 435
1 holder for beam divider	473 43
1 film holder	473 44
1 object holder	473 45
2 spherical lenses, 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:

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.

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 into 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.

Dark objects should be sprayed with brighter colors to take advantage of the full laser power.

Treating 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 optical components 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 soiled lenses from their holders and polish them 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.

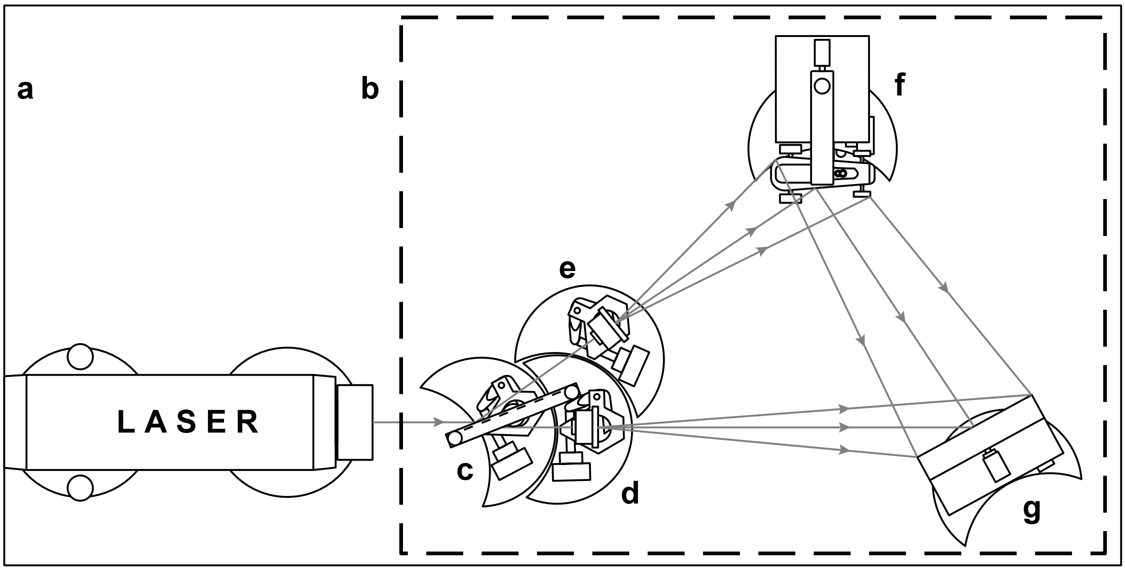

Fig. 2: Experiment setup for creating transmission holograms on the laser optics base plate
a laser optics base plate
b protective cover
c variable beam divider
d, e spherical lenses
f object holder
g film holder

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.

Adjusting the variable beam divider:

Notes:

The greater the angle of incidence of the laser beam is on the variable beam divider, the closer the object can be placed to the laser in the subsequent experiment (better utilization of laser power). However, the transmitted main beam must exit the beam divider on the opposite side (and not the end face!).

In spite of the broad-band antireflective coating of the beam divider, parasitic beam components are created due to multiple reflection, in addition to the transmitted main beam; however, these are screened out by the lens holder.

The division ratio of the beam divider varies over its width. You can change the intensity ratio of the two partial beams by moving the beam divider perpendicular to the original laser beam. As a great deal of energy can be lost at the object due to diffuse and weak reflection, you should set the division ratio in favor of the object beam from the very beginning.

– Check whether the beam divider **(c)** reflects the laser light horizontally. To do this, place the beam divider with holder and optics base in the beam path at the opposite end of the laser optics base plate and reflect the light beam to a point next to the emission aperture of the laser.
– If necessary, correct the angle of inclination of the beam divider, and thus the beam path, using the two screws on the rod.
– Place the beam divider with optics base in the beam path as shown in Fig. 1 so that its partially transparent layer is facing toward the laser and it is still possible to close the cover.

Lens holder and film holder:

– Place the object holder **(f)** in the reflected beam path.
– If possible, secure the object in the object holder using the retaining arm and position the object holder so that the beam strikes the object in the center.

– Place the film holder **(g)** in the transmitted beam path so that it faces toward the object, and it is still possible to close the cover.
– Insert a piece of white paper cut to size in the film holder and align the film holder so that the beam strikes the center of the paper (and later, the film).

Spherical lens of reference beam:

Note: The quality of the reference beam is especially important for the quality of the hologram. Thus, the reference 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 lenses or beam divider.

– Place the spherical lens **(d)** in the transmitted beam as close as possible to the beam divider (the small opening of the lens holder must face toward the beam divider). Use the notches in the optics bases.
– Adjust the spherical lens by carefully moving it perpendicular to the beam path, by turning the base on its own axis and by changing the height of the lens holder so that the laser beam passes through the lens as nearly axially as possible, and that the object receives as much light as possible when viewed from the film holder. Be sure not to disturb the beam divider.

Spherical lens of object beam:

– Place the spherical lens **(e)** in the transmitted beam as close as possible to the beam divider (the small opening of the lens holder must face toward the beam divider). Use the notches in the optics bases.
– Adjust the spherical lens by carefully moving it perpendicular to the beam path, by turning the base on its own axis and by changing the height of the lens holder so that the laser beam passes through the lens as nearly axially as possible, and that the object receives as much light as possible when viewed from the film holder. Be sure not to disturb the beam divider.

Note: only those points which are illuminated will be visible on the hologram.

Fine adjustment:

– Switch the laser to 1 mW power and check the quality and beam path of the widened partial beams. If necessary, readjust the lenses.
– In a darkened room, interrupt the object beam and the reference beam and compare their brightnesses when incident on the white piece of paper mounted in the film holder.

The intensity relationship is best when the reference beam is five to ten times more intensive than the beam deflected from the object onto the film. This can be estimated sufficiently accurately with the naked eye.

– If necessary, readjust the division ratio at the beam divider; to do this, remove the spherical lenses with their optics bases from the beam path, and readjust the whole system.

If, due to the acute angle of incidence, the transmitted laser beam in the desired division ratio emerges from the matte end face of the beam divider instead of from the opposite side:

– Insert the beam divider in its holder turned 180° (reverse it from left to right; the mirrored side still faces toward the laser!). As always, do not touch the glass surfaces with your bare fingers; use cotton gloves or a lint-free cloth.

In the case of highly reflective objects, the hologram will be more attractive if the main reflections do not fall directly on the film.

– You may want to turn the object slightly.
– Remove the paper from the film holder.

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 **(g)** 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 5 s to 15 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. To do this, you must insert it in the film holder in the same orientation as during holography. Then put the film holder back in the setup, and remove the object. When the laser is switched on, the three-dimensional image of the object can be observed.

If the reconstructed hologram is not bright enough, you can increase the brightness somewhat by varying the division ratio of the beam divider or removing it completely from the experiment setup. This is recommended particularly for the less bright amplitude holograms. You may need to readjust the laser to compensate for parallel shifting.

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.

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