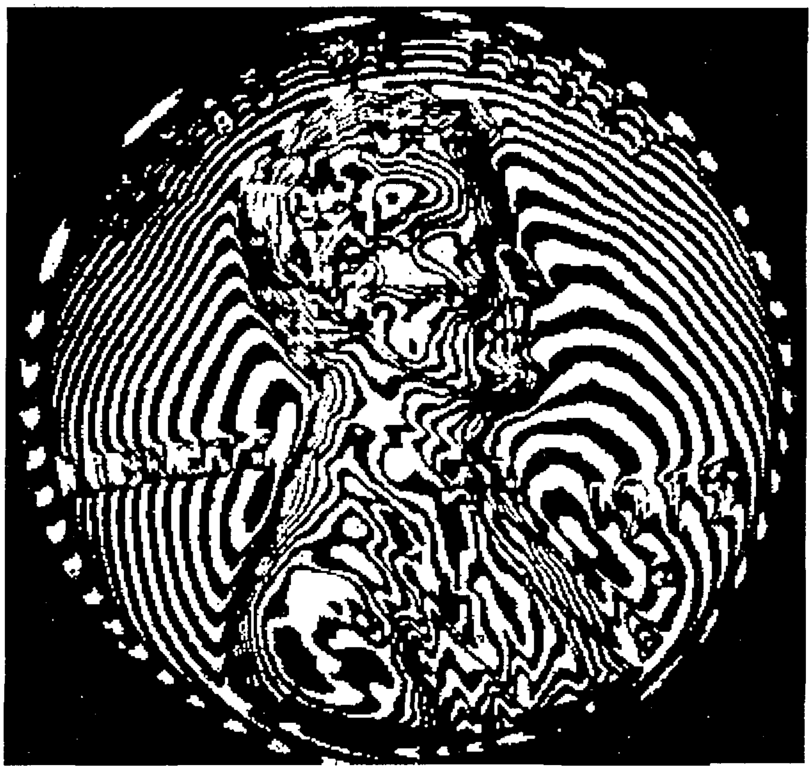
Holographic Interferometry of Mono- and Bimetallic Pennies



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EE 488 Project Proposal, 2/12/95

What's with the penny?

Metal expands when heated. Using two types of pennies as subjects, we plan to measure the amount of that thermal expansion using interference holograms, such as that shown above (from [1], p. 610).

The U.S. Mint made pennies from a copper alloy (97% Cu, 5% Zn) until 1983, when they switched to copper-plated zinc (2.5% Cu, 97.5% Zn) [2, 3]. We expect to see different heating effects in the two types of pennies. For the alloy penny, we expect to see straightforward expansion of the metal, in proportion to the thermal expansion coefficient of copper. For the bimetallic penny, however, we expect that the stress on the joint between the two metals will cause a much greater effect. This effect will show up as fringes on our interference hologram.

Procedure

We will first cool the penny with liquid nitrogen and make the initial hologram. Then we will wait until the penny has warmed to room temperature, and take the second hologram. In this manner, we hope to avoid any movement of the penny due to physical contact. We will try to use a standard laboratory three prong holder to keep the penny stationary. Alternatives include a lens holder or a custom designed penny vise.

The thermal coefficient of expansion of copper is 17 microns/m K [4]. If a penny's thickness is 1 mm, and experiences a change in temperature of approximately 100 K, we expect a change in thickness of approximately 1.7 microns. This corresponds to about three wavelengths of 633 nm laser light.

We will first attempt double exposure reflection holograms, which send one beam of light to each side of a photographic plate. We will then try double exposure transmission holograms, which send both beams to the same side of the plate. If we succeed at these, we will try real time interference holograms, in which a double exposure is NOT made. Instead, a single hologram is exposed, developed, and is replaced in the exact position in which it was exposed. The reconstructed hologram of the object will fall exactly upon the object itself, and any slight distortion of the object will show up as fringes visible in real time. Due to exacting repositioning requirements, successful real time holography may require special techniques, described below in the section on photographic processing.

Optics of Holographic Interferometry

What is a Hologram? [1]

What we can see in a photograph is the recorded image of reflected light from the object. However, a photograph only records the intensities of the light (Fig. 1). Therefore, the wavefronts from a photograph are incomplete, as compared with the original light. This causes a viewer to see the object only from a certain perspective.

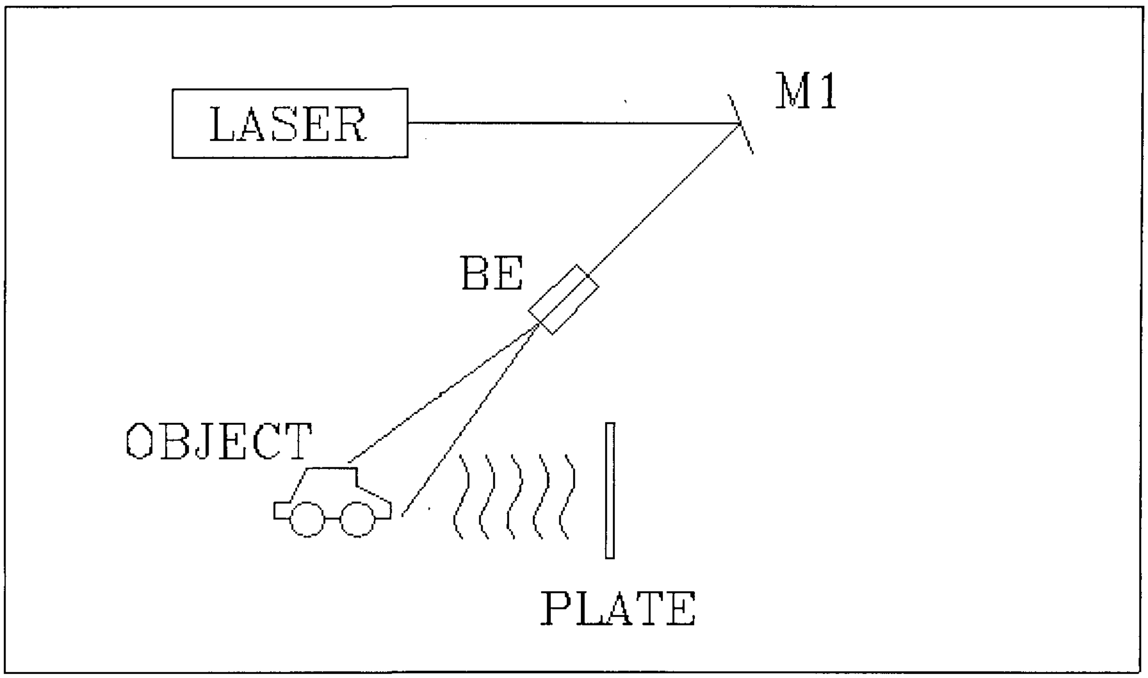


Figure 1. Conventional 2-D photography.

A hologram is created by recording the interference patterns produced by the object light and the reference light (Figs. 2, 3). In this way the plate not only records the intensities of the light, but also the phase differences. After the hologram plate is processed, we use the same reference light to recreate wavefronts of light just as if they were coming from the original object.

Holograms can be divided into two groups by their different image recording and reconstruction methods. In the reflection hologram as shown in Fig. 2, the reference light and the object light shine on opposite faces of the hologram plate, so the image is reconstructed by the reflection of the reference light.

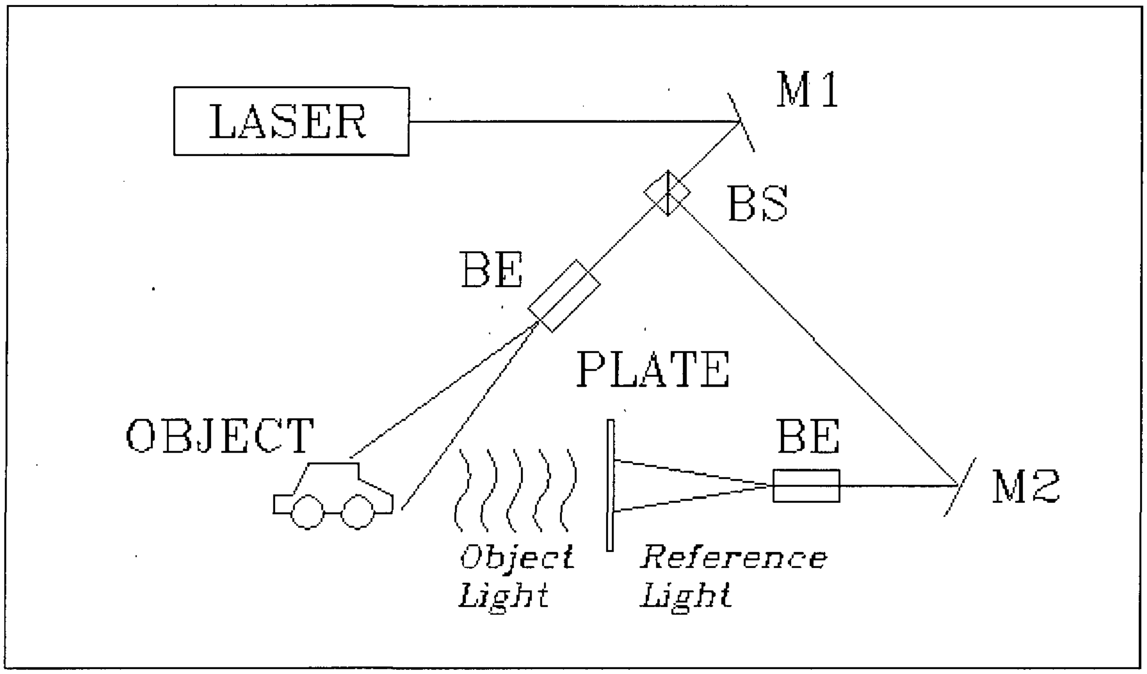


Figure 2. Reflection Holography.

In the transmission hologram (Fig. 3), the reference light and the object light shine on the same face of the plate, and the viewer sees the image reconstructed by transmission of the reference light through the plate.

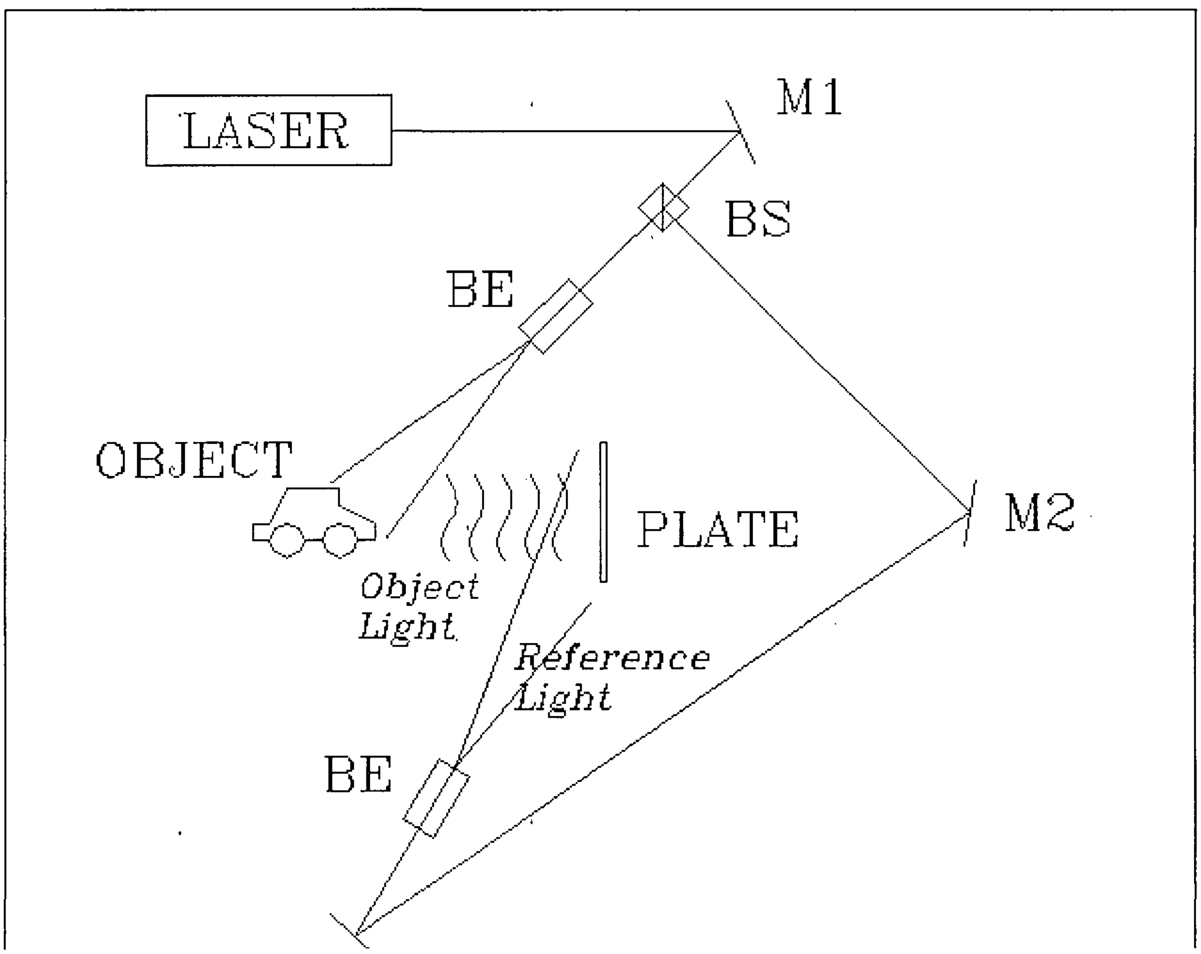


Figure 3. Transmission Holography.

What is an interference hologram?

Interference holograms result from the superposition of two or more holograms on the same photographic plate. Figure 4 represents a standard hologram in which areas of constructive and destructive interference between the object and reference beams are represented by red and black concentric circles.

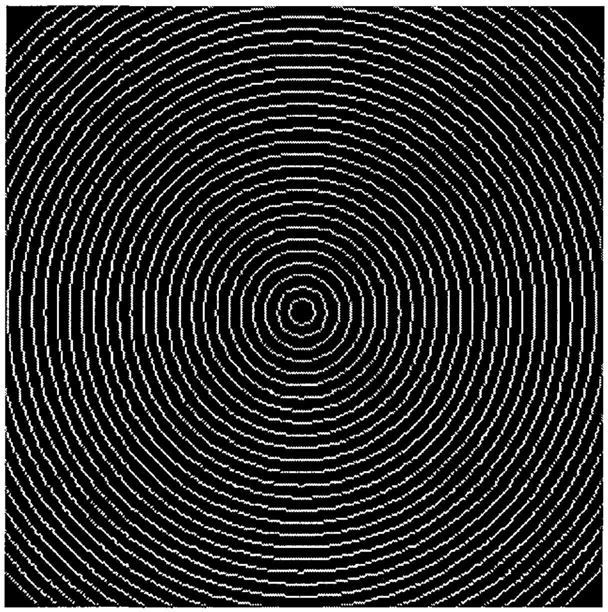


Figure 4. Schematic drawing of a hologram

Figure 5 represents an interference hologram in which a second, slightly different standard hologram is exposed on the same photographic plate. The result is a set of patterns related to the interference of the two holograms. This example shows interference caused by translation of the object hologrammed. Our interference patterns will be related to thermal expansion.

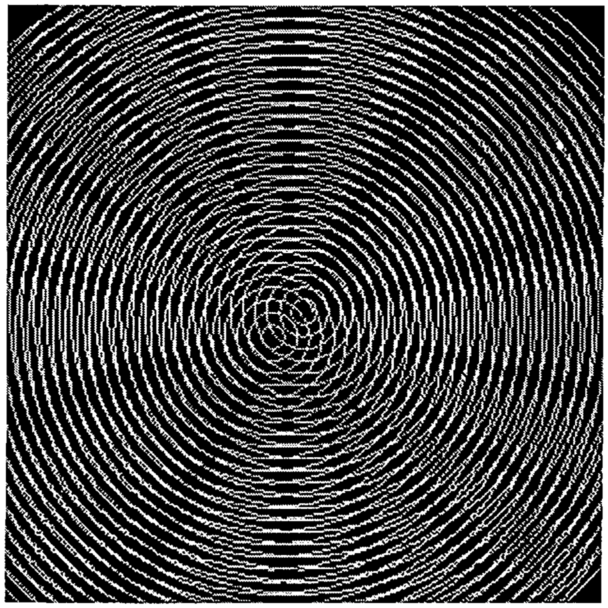


Figure 5. Schematic drawing of an interference hologram

The simplest type of holographic interferometry is the double exposure method. We make a hologram by exposing the object to the light twice: first when the object is undisturbed, then while the object is distorted. These two holograms interfere with each other and generate interference patterns when the image is reconstructed. Therefore, we can measure micro deformation by counting the fringes and calculating the optical path difference.

We will try to use two different types of methods:

Double exposure method

1. Make a hologram of the undisturbed object.
2. Distort the object.
3. Re-expose the hologram.
4. Process the hologram plate.

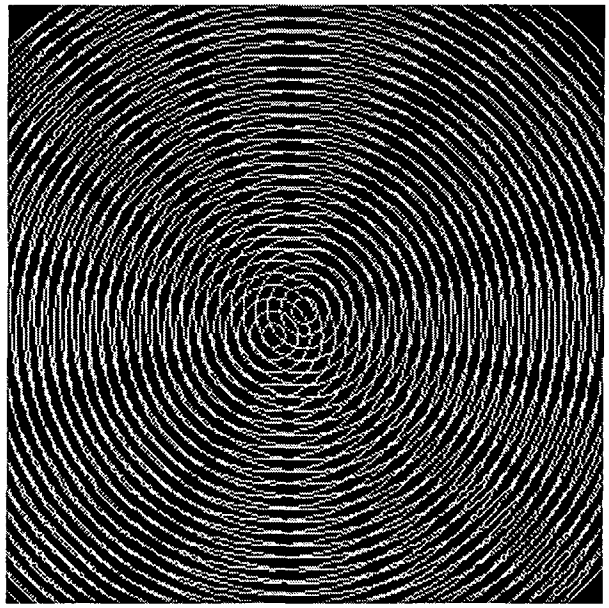
Real-time method

1. Make a hologram of the undisturbed object.
2. Process the hologram plate.
3. Put the processed hologram back in place.
4. Distort the object, and observe interference fringes.

The second method has the advantages that in real time, different types of distortion can be applied and motion pictures can be taken.

Important Optical Issues:

1. The direction of the reference wave should be well separated from that of the object waves, so that the viewer can see the reconstructed image without being in the direct path of the reference laser beam.
2. Since the hologram plate records the relative intensities rather than absolute intensities, the reference light should shine uniformly on the plate.
3. The object wave and the reference wave exposing the plate must be mutually coherent to result in the interference pattern, that is, the optical path length of both light beams should be the same.
4. The interference pattern must remain stationary during the exposure period. Therefore, the stress



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on the penny must be constant throughout the exposure.

Spatial Filtering

Spatial filtering is a method used to eliminate the dark swirls in the illumination patch of the expanded laser beam. These swirls are caused by the interference of the parts of the beam that have been diffracted by dust and imperfections in the laser or optical components.

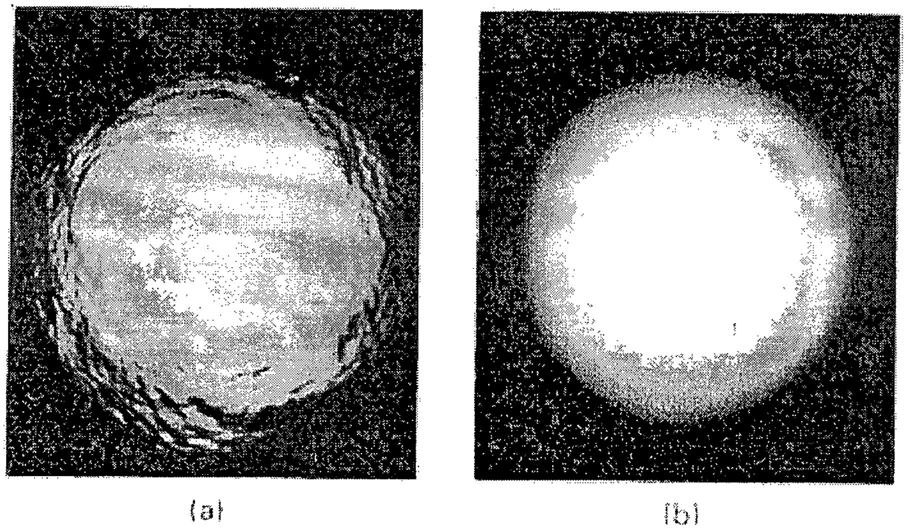

Figure 6. Appearance of laser beam (a) before and (b) after spatial filtering. (from [5], p. 91.)

A spatial filter is composed of a convex lens and a pinhole. The lens works as a Fourier transformer to convert the beam to the spatial frequency domain on the focal plane, and the pinhole works as a low pass filter which removes the undesired high frequency components.

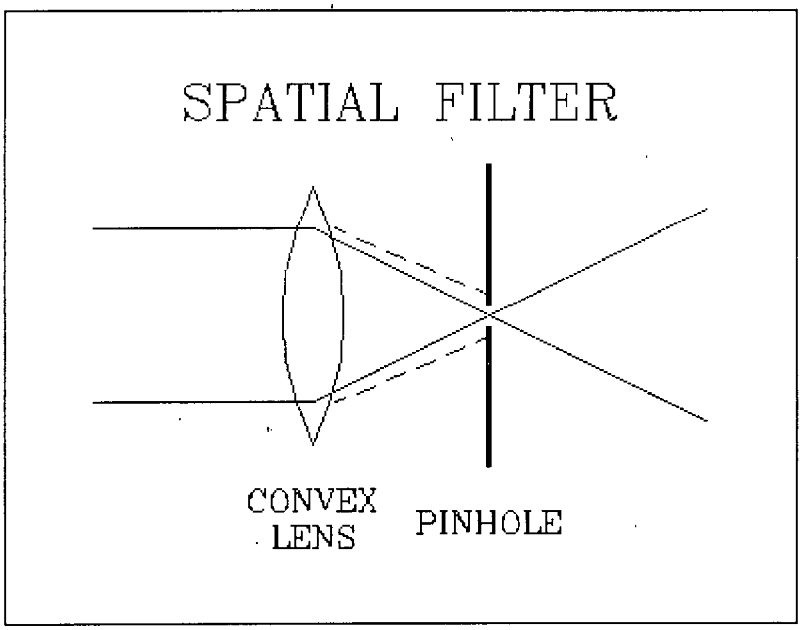

Figure 7. Spatial Filtering.

Use of a spatial filter can result in a cleaner holographic image. However, it also reduces the amount of light which strikes the plate. Spatial filters are likely not necessary for our purposes, but we will keep them in mind.

Photographic Processes for Holographic Interferometry

The photographic process used in holography is very similar to the conventional process used for black-and-white photography. The main difference is that a hologram must record images of much higher resolution: it must be able to resolve features as small as the wavelength of light that is used. This can be seen in figure 8, which shows an electron microscope image of a cross-section of a holographic emulsion. The fringes stored in the hologram are spaced about 1 micron apart.

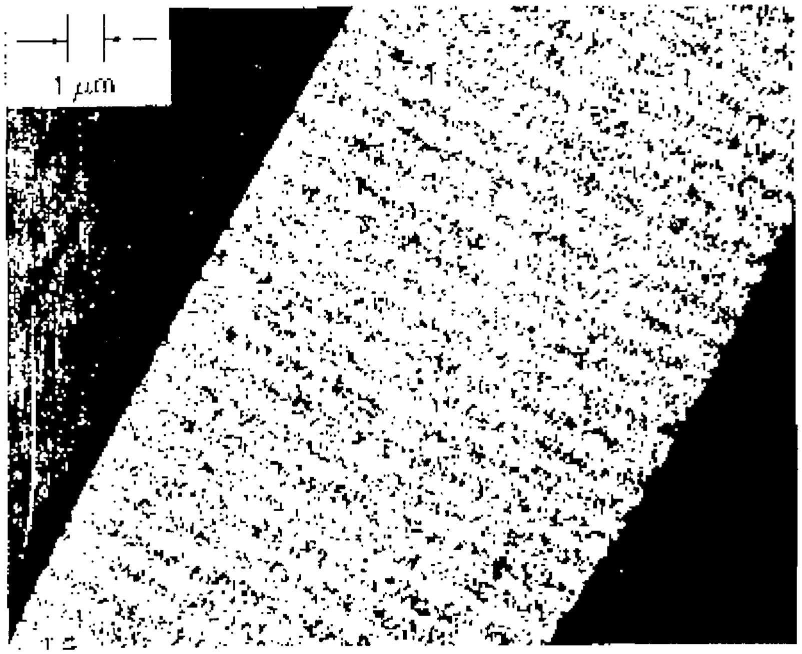

Figure 8. Cross section of a holographic emulsion. ([7], p. 195.)

The recording of such fine detail requires special emulsions (about 10 times the resolution, and 1000 times slower than conventional films [7, p. 349]) and great stability of the holographic setup, to prevent any blurring of detail.

Step by Step Photoprocessing

1. Prepare plate. We will be using Agfa 8075HD 4" x 5" glass plates.
2. Hold plate. Positioning of the plate must be stable and repeatable. We will use a commercial holographic plate holder.
3. Expose plate. Typical exposure times are ~10-60 seconds. We will initially determine the correct exposure by test strip, and verify successive exposures using a light meter. We will keep vibration as low as possible during the exposure. For double exposure interferograms, two exposures, probably of half normal exposure times, must be made.
4. Process plate. Temperature of all solutions should be kept stable, around 20 C.
    1. Develop in D-19, 4-7 minutes.
    2. Rinse/Stop Bath, 30 seconds.
    3. Fix, Kodak Rapid Fixer, 5 minutes.
    4. Wash/Hypo Clearing Agent, 15 minutes or so.
    5. Bleach. This in an optional step, not used in conventional photography, in which the dark areas of the hologram are turned into clear areas with a high refractive index. This gives brighter, more easily visible holograms.

6. Dry.
5. Hold plate. For 'live' interferometry, repositioning must be exact.
6. View plate

Possible Difficulties

Double exposure holographic interferometry should be no more difficult than normal holography, with its usual concerns of vibration control, beam coherence, and exposure time. Our particular experiment has the complication that we are trying to heat or cool the subject of our hologram without moving or otherwise disturbing it (with liquid nitrogen, for example, frost could be a problem.) We will explore different ways of holding the penny and applying thermal stress.

We expect live holographic interferometry to be much more problematic, as the hologram must be moved and chemically processed between "exposures." Even if the plate itself can be repositioned exactly, changes in the emulsion during processing may have changed the stored hologram dramatically. For instance, the emulsion can absorb water during processing, causing a permanent swelling. Or, photographic processing may remove chemicals from the emulsion, causing a permanent shrinkage. As information in the hologram is stored not just on the surface, but throughout the thickness of the emulsion, as was shown in figure 8, a change in this thickness may change the information stored in the hologram.

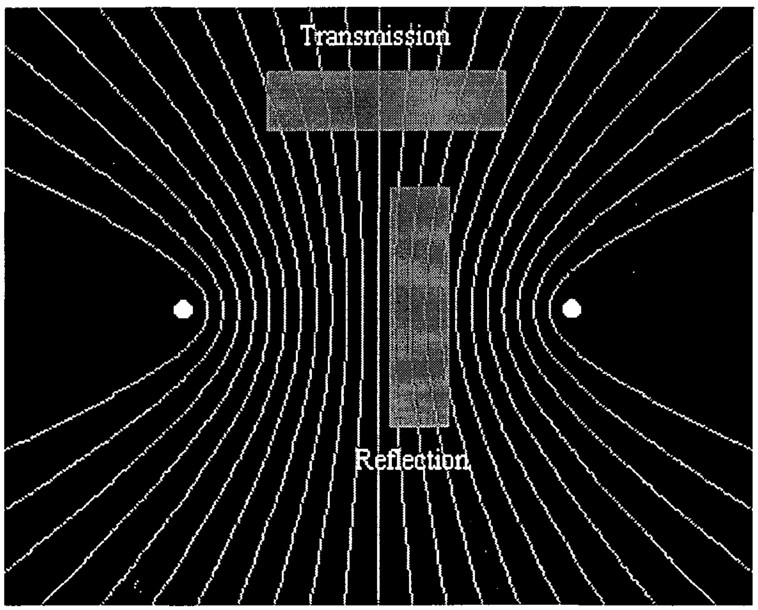

Figure 9. Fringe orientation in holograms

This tends to be a bigger problem for reflection than for transmission holography, as can be seen in figure 9. This figure shows two point sources of light, representing the object beam and the reference beam, and the interference fringes that result from interference between the two. For a transmission hologram, both beams are on the same side of the plate, and the fringes are mostly perpendicular to the emulsion surface. If the thickness of the emulsion was to change, it would not change the spacing of the fringes very much. For a reflection hologram, however, the beams are on opposite sides of the plate, and the fringes run parallel to the surface of the emulsion. A change in emulsion thickness would directly affect the spacing of the fringes, and have a large effect on the stored image.

Therefore, we will focus on transmission instead of reflection holography while attempting to do live interferometry. We may still have problems with emulsion changes during processing, however. One way to try to minimize these changes is to pretreat the emulsion before it is exposed. For instance, one might soak the plate in water to pre-swell the emulsion, in the hopes of eliminating any further swelling during processing. There seem to be a lot of subtleties involved, which we will address if they become an issue.

List of required materials, with purchase/rental costs

Item	Qty	Cost
5 mw Helium Neon Laser	1	$5.00
Laser mounts	1	-
Mirror holders	3	-
Pinhole spatial filters	2	-
Convex lenses	2	-
Microscope lenses	2	-
Beam splitter, 50%/50%	1	$1.00
Light baffles	2	-
Holographic plate holder	1	-
Lens mounts	2	-
Mirrors	2	-
Pennies	2	$0.02
Penny holder	1	-
Holographic plates	7-10+	-
D-19 developing solution	1	-
Bleaching kit	1	$15.00
Fixing solution	1	-
Polarizing sheet (2"x2")	1	-
815 Photodetector	1	$2.00
HeNe safety glasses	3	-

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