1
Introduction

With its many applications holography is one of the most interesting developments in modern optics. Its scientific importance is emphasized by awarding the 1971 Nobel prize to its inventor Denis Gabor. The term "holography" is a compound of the Greek words "holos = complete" and "graphein = to write." It denotes a procedure for three-dimensional recording and displaying of images and information without the use of lenses. Therefore holography opens up completely new possibilities in science, engineering, graphics and arts. Fields of applications are interferometric measurement techniques, image processing, holographic optical elements and memories as well as art holograms.

1.1
Photography and Holography

1.1.1
Object Wave

To see an object it has to be illuminated. In doing so light is scattered and a so-called object wave is created. This wave contains the complete optical information of the object. The light wave is characterized by two parameters: the *amplitude*, which describes the brightness, and the *phase*, which contains the shape of the object. In Fig. 1.1 two waves of different objects are shown which have the same amplitudes but different phases. The objects have the

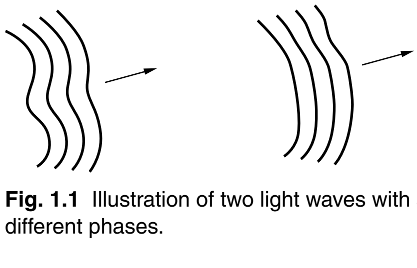

Fig. 1.1 Illustration of two light waves with same amplitudes but different phases.

Holography: A Practical Approach. Gerhard K. Ackermann and Jürgen Eichler

ISBN: 978-3-527-40663-0

same brightness but a different shape. For most holograms the color of the objects is not important, so the first chapters only deal with light waves of one wavelength. This changes for color holography which uses several wavelengths.

1.1.2 Photography

During the process of vision an object is imaged by the eye lens onto the retina. The optical path in a camera is similar: the objective creates an image on the film. For observation or to photograph an object it has to be illuminated. The scattered light, i.e., the object wave, carries the information of the object. The light wave can be made visible in a plane of the optical path, for example using a screen. The object wave appears as a very complex light field (Fig. 1.2) which results from the superposition of all waves emerging from the individual object points. If this light field could be recorded on a screen and displayed again, an observer (or a camera) would see an image that is not discriminable from the object [27].

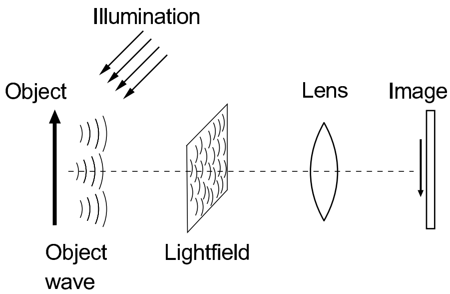

Fig. 1.2 Principle of the imaging process by a lens (camera or eye).

If there is a photographic film at the position of the screen, the object wave will cause a darkening distribution during the following processing of the film. But only the light intensity is recorded; all information of the phase in the plane of the screen is lost. This loss of phase also happens if the object is imaged onto a film by a lens. Therefore the object wave can never be completely restored from a normal photographic image. A two-dimensional image is the result.

1.1.3 Holography

Holography uses the properties interference and diffraction of light which make it possible to reconstruct the object wave completely. To be able to see these effects coherent laser light has to be used. “Coherence” means that the light wave is constant and contiguous. The laser on one hand illuminates the object and the scattered light hits the photographic film (object wave) (Fig. 1.3a). On the other hand, the film is illuminated directly with the same laser (reference wave). The object and the reference waves interfere with each other on the holographic film. This generates interference fringes in the holographic layer as are shown as a largely magnified image in Fig. 1.4. The distance of the fringes is in the region of μm which is in the order of magnitude of the light wavelength. The information of the object wave is contained in the modulation of the brightness of the fringes and in the distance of the fringes.

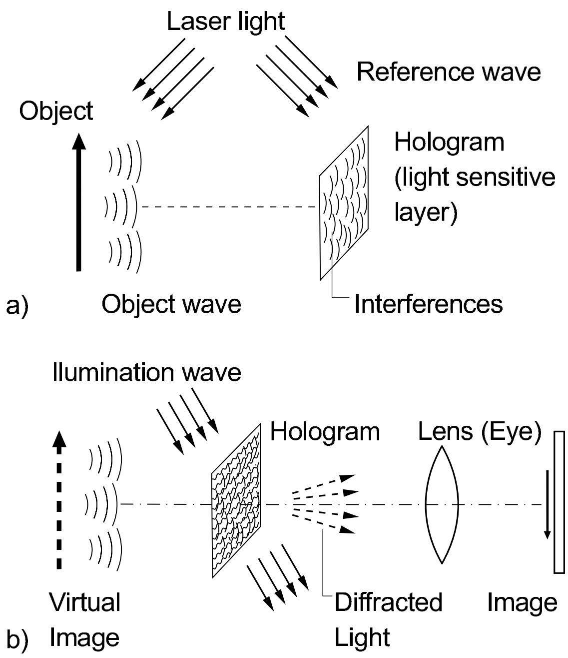

Fig. 1.3 Principle of two-stage imaging with holography: (a) recording of a hologram and (b) reconstruction of the object wave.

The photographic film is exposed and developed resulting in the hologram. The first step in holography, the *recording*, is made. The second step, the *reconstruction* or *display* of the object wave, is shown in Fig. 1.3b. After developing the film the hologram is illuminated with a light wave that should resemble the reference wave as best as possible. This reconstruction wave is diffracted by the interference pattern of the hologram generating the object wave. An observer looking at the hologram will see a three-dimensional image of the object.

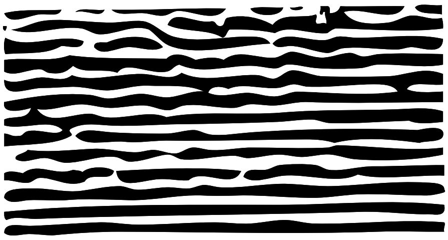

Fig. 1.4 Section of a microscopic image of a hologram.

1.2
Interference and Diffraction

1.2.1
Interference During Recording

Light is an electromagnetic wave ranging from 0.4 to 0.7 µm. In the following the superposition of two constants, i.e., coherent light waves, is described. This process, known as "interference," is responsible for the recording of holograms.

A general description of the waves emerging from the object is complicated. Therefore for simplification a plane object wave is considered. The object in this case is a single point at a large distance. According to Fig. 1.5a a plane object wave and a plane reference wave impinge on the photographic layer. The superposition of the waves creates equally spaced interference fringes, i.e., parallel bright and dark areas. Dark areas occur when the waves cancel out each other by superposition of a maximum and a minimum. Bright areas occur when maxima (or minima) of the waves are superimposed. After exposing and developing the photographic layer a grating is created where exposed areas appear dark.

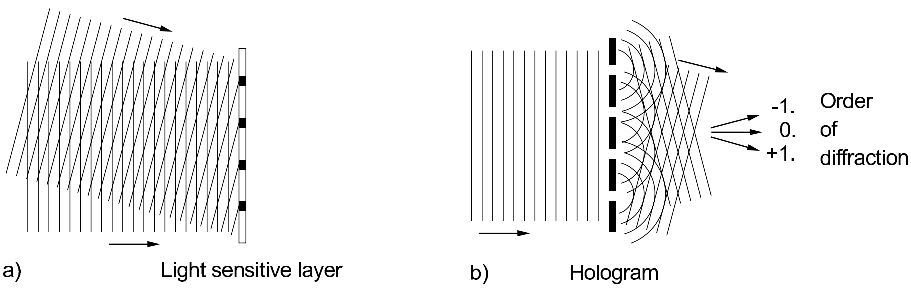

Fig. 1.5 Hologram with a plane object wave: (a) recording of the hologram (fabrication of a diffraction grating) and (b) reconstruction of the object wave (diffraction by the grating) [27].

1.2.2 Diffraction During Reconstruction

The image is displayed by illuminating the grating with a wave that closely resembles the reference wave (Fig. 1.5b). According to Huygens' principle each point of the grating sends out a spherical elementary wave. They are shown in Fig. 1.5b for the center of the bright fringes. The superposition of the elementary waves can be shown by their envelope. Plane waves are created which represent the 0th, 1st, and −1st diffraction orders [1]. (Higher order of diffraction does not occur in sinusoidal gratings.) The zeroth order is the wave passing the grating in the direction of the impinging wave. The first order represents the object wave.

Through the effect of diffraction the object wave is reconstructed; this is the principle of holography. The −1st order is often not desirable in this simple stage of holography; it is called the "conjugate object wave."

1.3 History of Holography

The physical basics of holography are optics of waves, especially interference and diffraction. The first achievements are that of C. Huygens (1629–1694), who phrased the following principle: *every point that is hit by a wave is the origin of a spherical elementary wave*. Using this statement a lot of problems of diffraction can be calculated by adding up the elementary waves. Important on the way of developing holography are also the works of T. Young (1733–1829), A.J. Fresnel (1788-1827) and J. von Fraunhofer(1877–1926). Already at the beginning of the 19th century enough knowledge was at hand to understand the principles of holography. A lot of scientist were close to the invention of this method: G. Kirchhoff (1824–1887), Lord Rayleigh (1842–1919), E. Abbe (1840–1905), G. Lippmann (1845–1921), W.L. Bragg (1890–1971), M. Wolfke and H. Boersch. But it took until 1948 when D. Gabor (1900–1979) realized the basic ideas of holography.

The origin of holography was at first connected to problems in optics of electrons. Gabor made his first groundbreaking experiments using a mercury vapor lamp. At the beginning the holographic technique was of minor importance and was forgotten for some time. It was not until the coming up of laser technology when developments in holography experienced a significant upturn. So 23 years after his experiments Gabor was awarded the Nobel prize in 1971. In 1962 the theoretical aspects of this methods were refined by E. Leith and J. Upatnieks and a year later they showed off-axis holograms. This technique marks the breakthrough for the practical application of holography.

Problems

Problem 1.1 What are the two essential elements, which describe an electromagnetic wave?

Problem 1.2 Considering the two elements mentioned in Problem 1.1, what is stored during exposure of a photograph and a hologram and what is the reason of the different results?

Problem 1.3 How is the phase of the object wave preserved during holographic exposure? Name the basic optical principles for exposure and reconstruction of a hologram.

Problem 1.4 Would it help to use coherent light in a photographic exposure in order to get a three-dimensional image?