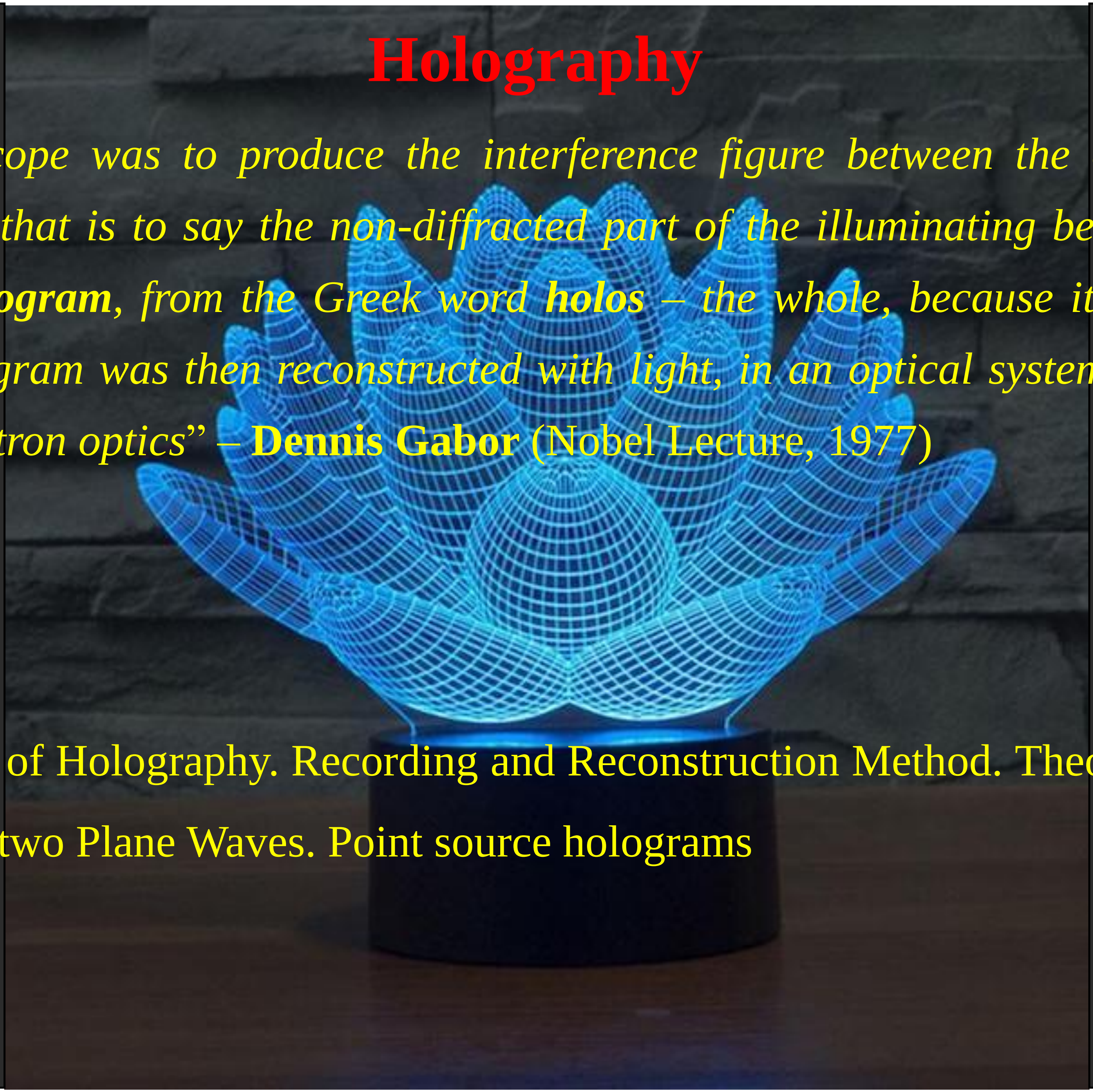
Holography

“The electron microscope was to produce the interference figure between the object beam and the coherent background, that is to say the non-diffracted part of the illuminating beam. This interference pattern I called a ***hologram****, from the Greek word* ***holos*** *– the whole, because it contained the whole information. The hologram was then reconstructed with light, in an optical system which corrected the aberrations of the electron optics”* – **Dennis Gabor** (Nobel Lecture, 1977)



Syllabus: Principle of Holography. Recording and Reconstruction Method. Theory of Holography as Interference between two Plane Waves. Point source holograms

Holography

What is holography?

- A hologram is an image that appears to be three dimensional and can be seen with the naked eye.
- Hologram is a photographic recording of a light field, rather than an image formed by a lens.
- Holography is the science and practice of making holograms.
- It is an encoding of the light field as an interference pattern of variations in the opacity, density, or surface profile of the photographic medium.
- The basic idea is that for perfect optical imaging, the total of all the information has to be used; not only the amplitude, as in usual optical imaging, but also the phase.
- The holographic medium, i.e., the object produced by a holographic process (which itself may be referred to as a hologram) is usually unintelligible when viewed under diffuse ambient light.

Holography

What is holography?

- When suitably lit, the interference pattern diffracts the light into an accurate reproduction of the original light field, and the objects that were in it exhibit visual depth cues such as parallax and perspective that change realistically with the relative position of the observer. That is, the view of the image from different angles represents the subject viewed from similar angles.
- In its pure form, holography requires the use of laser light for illuminating the subject and for viewing the finished hologram.
- The technique of holography can also be used to optically store, retrieve, and process information. While holography is commonly used to display static 3-D pictures, it is not yet possible to generate arbitrary scenes by a holographic volumetric display.

Holography

History

- Holography was invented in 1947 by Hungarian physicist Dennis Gabor (Nobel Laureate, Physics 1971)
- Gabor’s work was based on electron microscopy
- Leith and Upatnieks (1962) applied laser light to holography – required laser light to view the holographic image
- Benton in 1969 invented ‘Rainbow Holography’ for display of hologram in white light

Holography

Conventional vs. Holographic Photography

❖ **Conventional Photography**

- 2d version of a 3d scene
- Photograph lacks depth perception
- Film sensitive only to radiant energy
- Phase relation (i.e. interference) are lost

Holography

Conventional vs. Holographic Photography

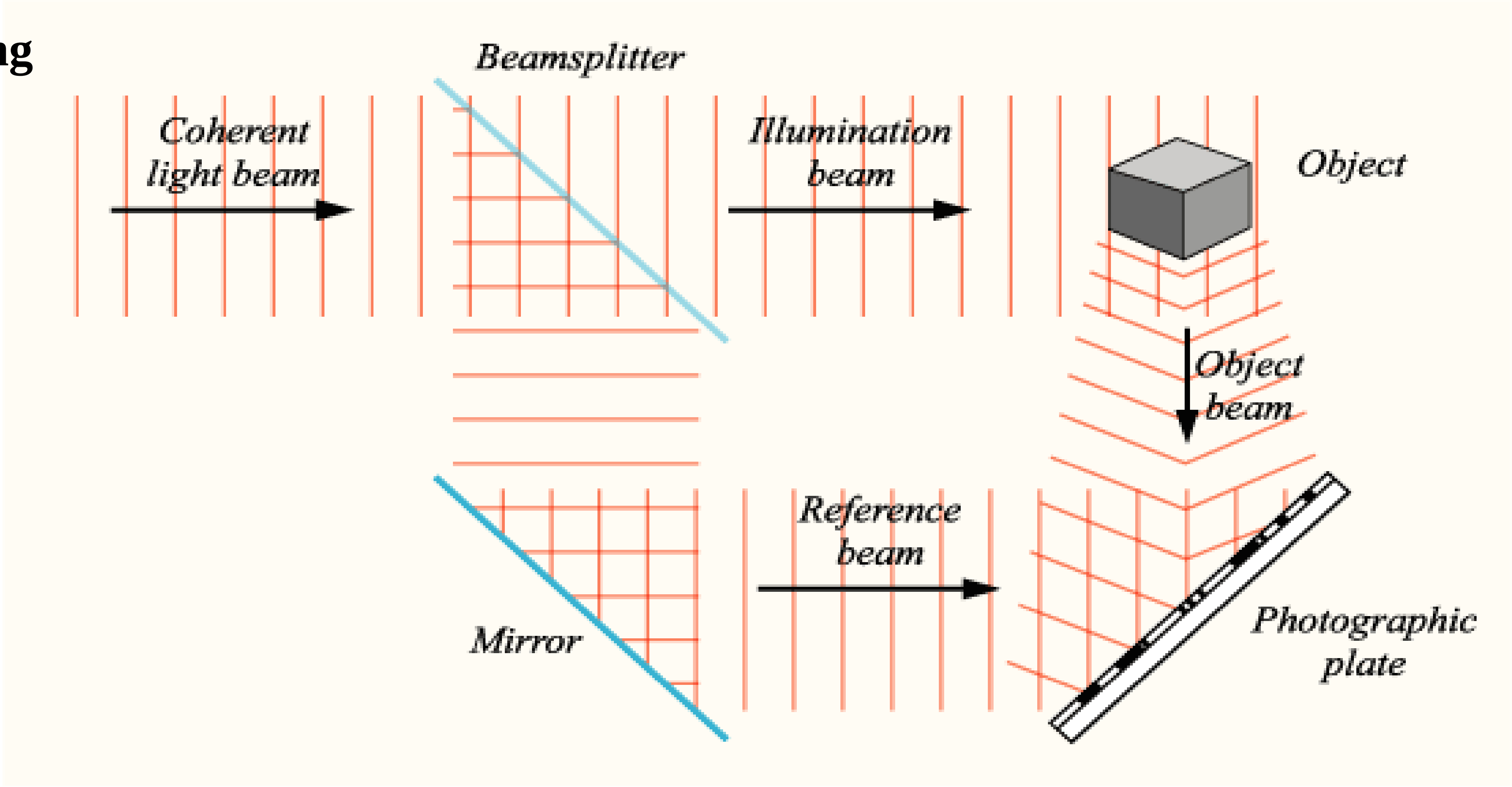
❖ Hologram

- ❑ Freezes the intricate wavefront of light that carries all the visual information of the scene
- ❑ To view a hologram, the wavefront is reconstructed
- ❑ View what we would have seen if present at the original scene through the window defined by the hologram
- ❑ Provides depth perception
- ❑ If you look at these holograms from different angles, you see objects from different perspectives, just like you would if you were looking at a real object
- ❑ They usually just look like sparkly pictures or smears of color
- ❑ If you cut one in half, each half contains whole views of the entire holographic image.

Holography

Working

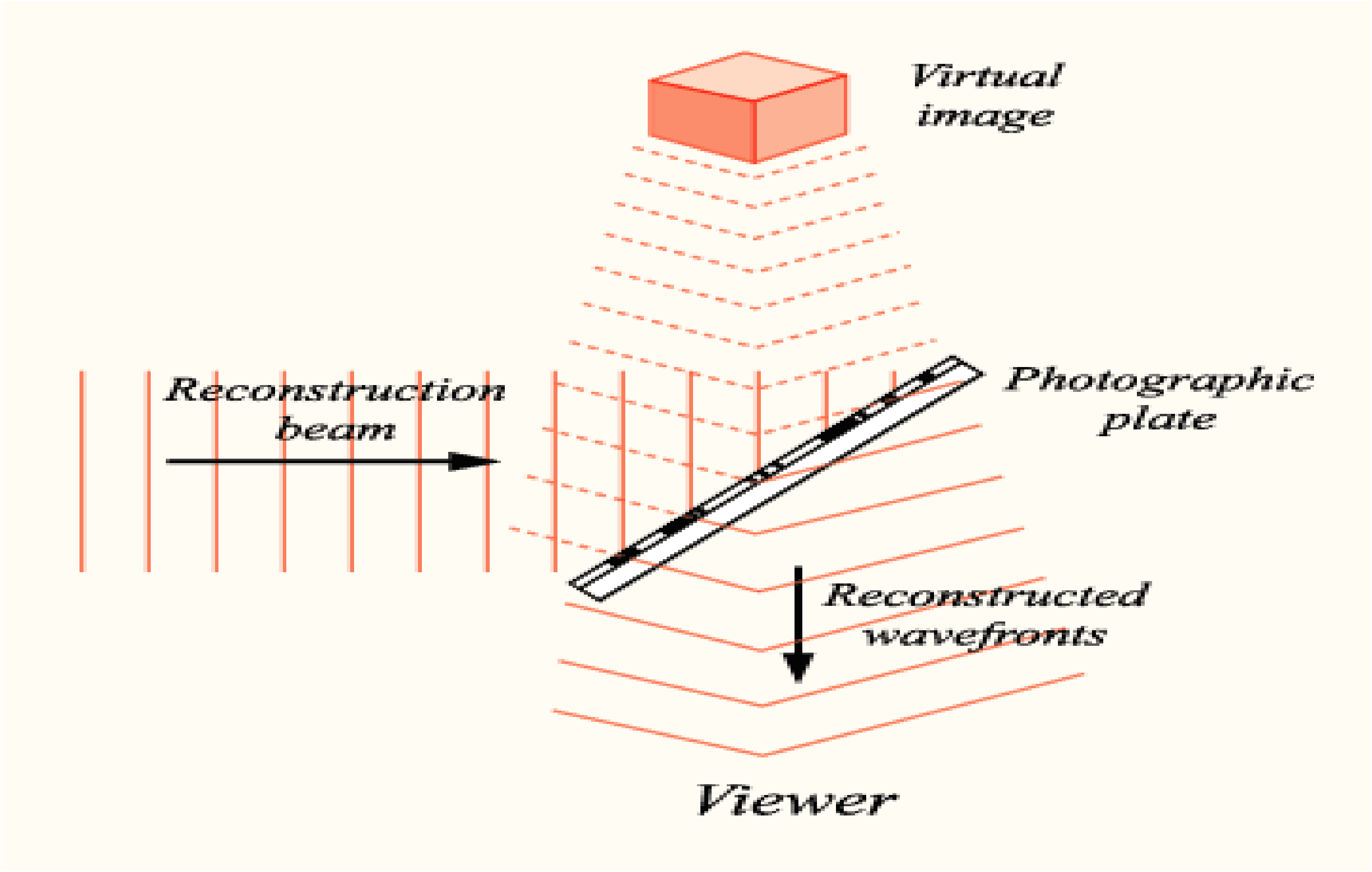
A. Recording



Holography

Working

B. Reconstruction



Holography

Mathematical Theory

Object beam amplitude: $a = a_0 e^{i\psi}$ Reference beam amplitude: $r = r_0 e^{i\phi}$

Superposed beam amplitude: $R = a + r$

Superposed beam Intensity: $I = kRR^* = k(a+r)(a^*+r^*) = k(aa^* + rr^* + ar^* + a^*r)$

$$= ka_0^2 + kr_0^2 + 2ka_0 r_0 \cos(\phi - \psi)$$

$$= \underbrace{I_o + I_r}_{\text{Sum}} + \underbrace{2\sqrt{I_o I_r}\cos(\phi - \psi)}_{\text{Interference term}}$$

Recording on the holographic film is dependent on the intensity *I*. Thus the information about the object beam is stored in the photographic layer

Holography

Mathematical Theory

Transmitted light amplitude: $A = k'rI = k'r(aa^* + rr^* + ar^* + a^*r)$

$$= k'r(a_0^2 + r_0^2 + ar^* + a^*r)$$

$$= k'\left[r_0^2(a + r) + a_0^2 r_0 e^{i\phi} + a^* r_0^2 e^{i2\phi}\right]$$

- **First Term:** Wavefront with complex amplitude proportional to that of the original wave amplitude – produces 3D virtual image
- **Second Term:** Modified version of the reference wave – negligible if reference wave is strong
- **Third Term:** Proportional to the conjugate of the object wave amplitude – generates real image in the space beyond the holographic plate

Holography

Point Source Hologram

Point source at a distance d from the photographic plate (xy plane, $z = 0$)

Object wave: $O(x, y, z=0, t) = \dfrac{A}{r}\cos(kr - \omega t)$, $\quad r = \left(x^2 + y^2 + d^2\right)^{1/2}$

Reference wave – plane wave travelling along z axis: $R(x, y, z, t) = B\cos(kz - \omega t)$

Reference wave on the plane of photographic plate ($z = 0$): $R(x, y, z=0, t) = B\cos\omega t$

Resultant wave on the plane of photographic plate ($z = 0$):

$$T(x, y, z=0, t) = O(x, y, z=0, t) + R(x, y, z=0, t)$$
$$= \frac{A}{r}\cos(kr - \omega t) + B\cos\omega t$$

Holography

Point Source Hologram

$$I(x,y,z=0)=\left\langle \left|T(x,y,z=0,t)\right|^2 \right\rangle = \left\langle \left|\frac{A}{r}\cos(kr-\omega t)+B\cos\omega t\right|^2 \right\rangle$$

$$=\frac{A^2}{r^2}\left\langle \cos^2(kr-\omega t)\right\rangle + B^2\left\langle \cos^2\omega t\right\rangle + \frac{2AB}{r}\left\langle \cos(kr-\omega t)\cos\omega t\right\rangle$$

$$=\frac{A^2}{2r^2}+\frac{B^2}{2}+\frac{AB}{r}\cos kr$$

Assume $d \gg x, y$: $\quad r=(x^2+y^2+d^2)^{1/2}=d\left(1+\frac{x^2+y^2}{d^2}\right)^{1/2}\approx d+\frac{x^2+y^2}{2d}$

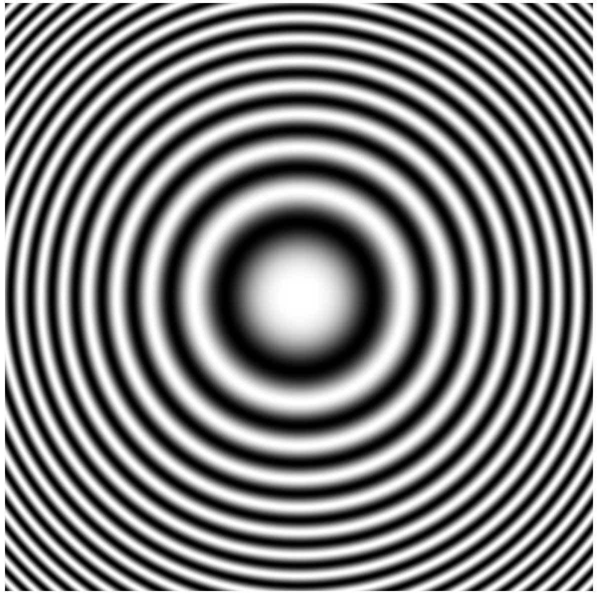
$$I(x,y,z=0)=\frac{A^2}{2r^2}+\frac{B^2}{2}+\frac{AB}{r}\cos\left[kd+\frac{k}{2d}(x^2+y^2)\right]$$

Holography

Point Source Hologram

$$I(x, y, z=0) = \frac{A^2}{2r^2} + \frac{B^2}{2} + \frac{AB}{r}\cos\left[kd + \frac{k}{2d}(x^2 + y^2)\right]$$

- Resultant fringe pattern is circular and centered at the origin
- Hologram formed in this manner is essentially a zone plate with the transmittance varying sinusoidally (in contrast to Fresnel zone plate)



Holography

Requirements

- Coherence

  - The maximum path difference between the object wave and the reference wave must be within the coherence length
  - Spatial coherence is also important so that waves scattered from different regions of the object could interfere with the reference wave

- Reconstruction

  - Reconstructed image depends on wavelength and the position reconstructing source.
  - For good resolution in the reconstructed image, the source must not be broad and should have good monochromaticity

Holography

Requirements

- Reconstruction process has associated aberrations as in images formed by lens
- For an aberration-free reconstructed image, the reconstruction source should have same wavelength (as that during recording) and is situated at the same relative position with respect to the hologram as the reference source

❑ Recording Arrangement

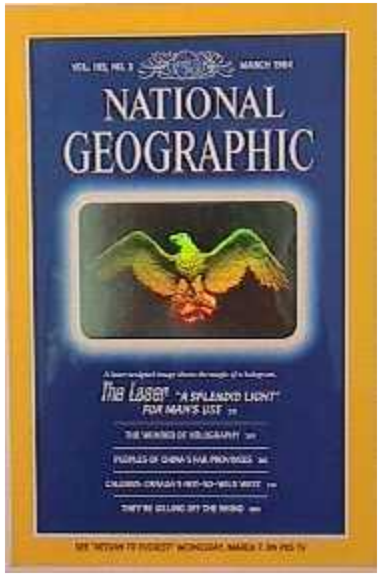
- Arrangement must be stable – object and mirrors used in recording process must be motionless
- Film resolution: Let two plane waves make angles $+\theta$ and $-\theta$ with the axis and produce an interference pattern with spacing $d = \lambda/2\sin\theta$. $d \approx 10^{-3}$ mm (for $\lambda \approx 600$ nm, $\theta \approx 15°$). Thus the photographic plate should be able to record fringes separated below 10^{-3} mm.

Holography

Applications

- ❑ Holographic Memory
- ❑ Interferometric Microscopy
- ❑ Holographic Interferometry
- ❑ Security
- ❑ FMCG Industry
- ❑ Art

Identigram as a security element in a German identity card



Hologram stickers engraved on magazine

Hologram stickers engraved on credit cards

Holography

Resources

1. Optics (3rd Ed.) by Ajoy Ghatak (Mc-Graw Hill)
2. A Text Book on Light by B. Ghosh, K. G. Mazumdar (Sreedhar)
3. https://en.wikipedia.org/wiki/Holography
4. Optical Holography: Ajeya Karajgikar, Georgia Institute of Technology