



**WAVE RECONSTRUCTION
IMAGING(HOLOGRAPHY) AND ITS
APPLICATION**

By

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Abstract

The three dimensional imaging holography has many application in physics and other science ,as a result many text describe the constructing and reconstructing techniques of different types of holograms .However; these descriptions are hard to understand easily and apply ,especially in our country Ethiopia .Since there are no trends actually done on the applications of holography , strong researches are not yet carried out ,and the subject not included in the curriculum for education in high schools and in university ,Hence in this project work I am interested to make it clear so that everyone can understand and use it effectively .

In this project work ,it tries to cover the basic theories,facts and principles of the physics of holography ,in addition to this the theoretical and the experimental backgrounds to make an advanced transmission hologram , how to reconstruct it and measure the image distance and height.Moreover; the lateral magnification elaborated qualitatively and quantitatively by reconstructing the transmission hologram , so as one can understand how we can able to determine the unknown wavelength of laser used in reconstruct the hologram but not in constructing the hologram.

Finally holography can be put to a variety of uses other than recording images. so the knowledge of holography is very important to our country to overcome problems in our day to day activities like holographic data storage technique that can store and others, then at the end of this project work i am tried to included some of the applications of holography.

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Introduction

”Everything should be made as simple as possible, but not simpler” - Albert Einstein However there are different methods and recording images (such as photography ,interferogram and so on).Here what I tried to show that how we can make a transmission type of hologram of where the objects are easily measurable and we can develop a three dimensional image by reconstruction and calculating the lateral magnification so that we can able to determine the wavelength of the unknown laser involved in reconstructing the hologram.

The first chapter deals with basic background for understanding interference pattern caused by two point sources of waves ,diffraction ,and diffraction grating as information carrier in optics .Moreover; a brief explanation of term that are used in the process like temporal coherence , spatial coherence , and coherence length , coherence volume.

The second chapter of this project work tries to explain a simple and brief explanation of laser beam the principles ,facts and ideas which are important for constructing wave fronts in hologram construction and reconstruction.At the end of the topic some of the applications of the lasers mentioned.

The third chapter tells about the central part of the project work ,here i tried to put forward the theoretical and experimental foundation of optical holography

(wave reconstruction imaging) from its historical background to its development. In addition to the different types of hologram there are also the preparation of the transmission hologram and reflection hologram discussed in brief . Mathematical expression on lateral magnification is also dealt widely.

The fourth chapter contains the procedure and the experimental setup that are used to construct the transmission hologram and the fifth chapter deals on results and discussion from the data measured and calculated and finally the conclusion part. At the last I tried to include some of the applications of holography.

Chapter 1

INTERFERENCE AND DIFFRACTION

1.1 Introduction

The process of producing a holographic is explained below purely in terms of interference and diffraction. It is somewhat simplistic, but is accurate enough to provide an understanding of how the holographic process works. The holographic process mainly the formation of hologram rests on two phenomena which are the consequences of wave nature of light i.e. Interference of light from two point's source and the principle of diffraction grating. Therefore in this chapter we will explain these two phenomena using proper approach to understand holography.

1.1.1 Interference of two point source

The term interference of two waves represents the appearance(overlap) of two or more waves which arrive at the same place in space. The consequence of interference is explained by the well known principle both in classical mechanics and quantum mechanics that is **superposition principle** can be stated as follows," The resultant

disturbance at point, where overlap of waves occurs, is the algebraic sum of the individual constituent waves at the location". that means

$$\vec{\psi} = \vec{\psi}_1 + \vec{\psi}_2 + \vec{\psi}_3 + \dots \quad (1.1.1)$$

The term disturbance stands to the physical quantity changing through time due to the existence of the wave. Therefore, using the basic concept of waves phenomena, interference at a point correspond to the resultant disturbance of the mixing of waves (disturbances). This resultant disturbance depends on the way of combination of two quantities, amplitude and phase. From this it is clear that there might be regions where two or more waves have overlapped partially or even completely cancel each other (**DESTRUCTIVE INTERFERENCES**). On the other hand there can exist regions where the resultant trough and crest are more pronounced than those of any constituent waves (**CONSTRUCTIVE INTERFERENCE**). These two patterns in relation with two point source interference are very important points for holography ; there for in this topic we will show how to determine the interference of two point source (light) that means using wave notation to formulate an equation which consists of each factors which are important to express interference by assuming that the waves as a plane wave. We can represent either as

$$\Psi(r, t) = A \cos(kr - \omega t + \Phi) \quad (1.1.2)$$

$$\Psi(r, t) = A \exp i(kr - \omega t + \Phi) \quad (1.1.3)$$

Where A- is the amplitude of wave $(kr - \omega t + \Phi)$ -is the phase, k -wave vector r -position vector ω -angular frequency Φ -initial phase angle.

Note the expression given in equation 1.1.2 the real part and in equation 1.1.3 the complex wave representation of waves. When we apply this wave representation to

our case, the optical disturbance here is the electric field E then the representation becomes

$$\vec{E} = E_o \cos(Kr - \omega t + \Phi) \quad (1.1.4)$$

$$\vec{E} = E_o \exp i(Kr - \omega t + \Phi) \quad (1.1.5)$$

Since the electric field strength E in electromagnetic waves changes very rapidly that it is not easily measurable, due to this reason the irradiance which corresponds to intensity (which is easily measurable and its relation with the optical disturbance E is simple) will be taken for treatment of interference. Here after a brief explanation on the relation between irradiance (I) of interference and the individual irradiance (I_1, I_2) can be shown. When we use equation (1.1.4) and (1.1.5) and using the fact that the time average energy carried by a wave is proportional to the amplitude, we have this relation

$$I \propto |E|^2 \propto \langle \vec{E} \cdot \vec{E} \rangle \quad (1.1.6)$$

i.e. the irradiance is proportional to the square of the amplitude of the electric field . Let us return back to our point, according to super position principle, the interference of different light waves at a point yields a resultant electric field E due to the separate fields E_1, E_2, \dots i.e

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \dots$$

Then the result of the interference of two points source S_1 and S_2 emitting monochromatic waves of the same frequency in a homogenous medium at a point (at position r_1 from S_1 and r_2 from S_2) becomes

$$\vec{E}(r, t) = E_{o1} \exp i(kr_1 - \omega t + \Phi_1) + E_{o2} \exp i(kr_2 - \omega t + \Phi_2)$$

Where r - is the position of P from some reference. Then to determine the irradiance at point P we must get $\langle E^2 \rangle = \langle E \cdot E^* \rangle$ since $E \cdot E = (E_1 + E_2) \cdot (E_1^* + E_2^*) = E_1 \cdot E_1^* + E_2 \cdot E_2^* + 2E_1 E_2 = I_1 + I_2 + I'$. Using the time averaged value it is clear that the irradiance due to the interference of the two point source emitting mono chromatic waves will be

$$I = I_1 + I_2 + I' \quad (1.1.7)$$

where

- I_1 = The irradiance from the first source S_1
- I_2 = The irradiance from the second source S_2
- I' = The irradiance from their combination

The last component (I') which comes to existence due to their combination is known as *interference term*. If we can simplify this term we can easily get the equation for interference of the two point source of mono chromatic waves

$$I = I_1 + I_2 + I' = \langle E_1^2 \rangle + \langle E_2^2 \rangle + 2 \langle E_1 E_2 \rangle$$

to solve $2 \langle E_1 E_2 \rangle$ let us evaluate values $\langle E_1 E_2 \rangle$, the time averaged value E_1, E_2

$$E_1 \cdot E_2 = E_{o1} \cdot E_{o2} (\cos(kr_1 - \omega t + \Phi_1)) (\cos(kr_2 - \omega t + \Phi_2)) \quad (1.1.8)$$

from trigonometry relation, we have that

$$\begin{aligned} \sin(\theta + \beta) &= \sin \theta \cos \beta + \sin \beta \cos \theta \\ \cos(\theta - \beta) &= \cos \theta \cos \beta + \sin \theta \sin \beta \end{aligned}$$

$$(1.1.9)$$

let it be

$$\theta_1 = kr_1 + \Phi_1$$

$$\theta_2 = kr_2 + \Phi_2$$

$$E_1 E_2 = E_{o1} E_{o2} [\cos \theta_1 \cos \omega t + \sin \theta_1 \sin \omega t] [\cos \theta_2 \cos \omega t + \sin \theta_2 \sin \omega t] \quad (1.1.10)$$

the evaluation result, we get

$$E_1 E_2 = E_{o1} E_{o2} [\cos \theta_1 \cos \theta_2 \cos^2 \omega t + \cos \theta_1 \cos \omega t + \sin \theta_2 \sin \omega t + \sin \theta_1 \sin \theta_2 \sin^2 \omega t] \quad (1.1.11)$$

+ $\sin \theta_1 \sin \omega t \cos \theta_2 \cos \omega t$] using the relation

$$\langle \sin^2(kr - \omega t + \Phi) \rangle = 1/2$$

$$\langle \sin \omega t \rangle = 0$$

$$\langle \cos \omega t \rangle = 0$$

by applying the above trigonometry relations the evaluating the time average values we get

$$\langle E_1 E_2 \rangle = E_{o1} E_{o2} [\cos \theta_1 \cos \theta_2 + \sin \theta_1 \sin \theta_2]$$

$$\langle E_1 E_2 \rangle = E_{o1} E_{o2} \cos(\theta_2 - \theta_1)$$

$$\langle E_1 E_2 \rangle = E_{o1} E_{o2} \cos k((r_2 - r_1) + (\Phi_2 - \Phi_1)) \quad (1.1.12)$$

Look carefully the final equation 1.1.12. The irradiance of the interference of the two point sources mainly depends on the third term especially on $k((r_2 - r_1) + (\Phi_2 - \Phi_1))$ (known as **phase difference**). There are situations to form a series of maximum and minimum irradiance for certain duration. It is that the difference in phase between the interfering waves S_1 and S_2 must be constant for that duration. The dark and

bright zones (minimum and maximum irradiance regions) of interference are known as *interference fringes*. This pattern is the back ground for hologram formation. Note: The time averaged value of a given function $f(t)$ is given by

$$\langle F(t) \rangle = \frac{1}{T} \int_t^{t+T} F(t) dt$$

which is taken over the interval $[t, t + T]$

1.2 Coherence length and coherence volume

We will now look on terms coherency, Coherence length, coherence volume, since these are necessary conditions to form a clear interference pattern. These terms are defined and explained by using interference of waves. Here we will take an extended source of light to define each term, so let us take a radiation emitted by an extended source S which generates a total field amplitude E at the point P, which is a super position of an infinite number of partial waves with amplitudes E_n and phase θ_n emitted from the different elements ds .

$$E(\vec{p}) = \sum E_n(p) \exp i \theta_n(p) = \sum \left[\frac{A_n(\theta)}{r_n} \right] \exp(i\Phi_{no} + 2\pi r_n/\lambda) \quad (1.2.1)$$

where $E_n(p)$ is the amplitude of the n^{th} partial wave at P due to the element ds , $\theta_n(p)$ is the phase of the n^{th} partial wave at P due to the element ds . If the phase difference $\Delta\theta_n = \theta_n(p, t_1) - \theta_n(p, t_2)$ at a given point P between different times t_1 and t_2 are nearly the same for all partial waves the radiation field is called **temporally coherent**. The maximum time interval $\Delta t = t_2 - t_1$, $\Delta\theta_n$ for all partial wave differ by less than π is termed as coherent time of the radiation source. The path length $c\Delta t = \Delta S_c$ is **the coherent length**. If a constant time independent phase difference $\Delta\theta_n = \theta(p_1) - \theta(p_2)$ exists for the total amplitude $E = E_o \exp i\Phi$ at two different

points P_1, P_2 the radiation field is called **spatially coherent**. All points which fulfill the condition that for all times t , $|\theta(p_m, t) - \theta(p_n, t)| < \Pi$ have nearly the same optical path difference from the source. They form coherence volume which can be expressed as the product of coherence length and coherence surface. Let us relate the above definitions with the previous topic interference consider two point sources emitting monochromatic wave of the same frequency. The interference term 1.1.12. at t_1 and t_2 becomes equal then

$$\begin{aligned} I'(t_1) &= E_{o1}E_{o2} \cos(k(r_2 - r_1) + (\varepsilon_2 - \varepsilon_1)) \\ I'(t_2) &= E_{o1}E_{o2} \cos(k(r_2 - r_1) + (\varepsilon'_2 - \varepsilon'_1)) \end{aligned} \quad (1.2.2)$$

Using the above definition if $t_2 - t_1$ is less than the coherence time then the phase difference in this time for each the waves at point of consideration, becomes equal to

$$\begin{aligned} \Delta\theta_2 &= kr_2 - \omega t_2 + \varepsilon'_2 - (kr_2 - \omega t_1 + \varepsilon_2) \\ \Delta\theta_1 &= kr_1 - \omega t_2 + \varepsilon'_1 - (kr_1 - \omega t_1 + \varepsilon_1) \end{aligned} \quad (1.2.3)$$

$$\Delta\theta_1 = \Delta\theta_2$$

$$\begin{aligned} \varepsilon'_1 - \varepsilon_1 - \omega(t_2 - t_1) &= \varepsilon'_2 - \varepsilon_2 - \omega(t_2 - t_1) \\ \varepsilon_2 - \varepsilon_1 &= \varepsilon'_2 - \varepsilon'_1 \end{aligned} \quad (1.2.4)$$

Note: Waves for which $\varepsilon_2 - \varepsilon_1$ is constant, regardless of its value are said to be coherent. This occurs only with the coherent time. Using the above explanation for the situation to get interference fringe, coherence time is the duration to get the interference pattern. The above relation clearly leads to the fact that for a fringe pattern to be observed, the two sources need not be in phase with each other a some

what shifted but otherwise identical interference pattern will occur if there is some initial phase difference between sources, as long as they maintain constant phase difference $\varepsilon_2 - \varepsilon_1$ must be constant. This shows the required fringes pattern occurs within the coherence length. Therefore the superposition of coherent waves results in interference phenomena, however; it can be observed directly only within the coherence volume. The dimension of this coherence volume depends on the size of the radiation source, on the spectral width of the radiation and on the distance between the source and observation point P. To get a more and clear explanation about coherence length, the factors affecting them we use the two well-known experiments, namely Michelson interferometer and Young's double slit interference experiment. The ar-

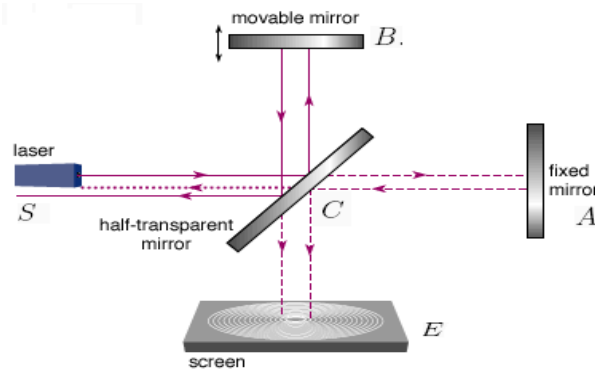


Figure 1.1: Michelson interferometer

angement for Michelson interferometer is in the above figure 1.1 where, S-the source of the beam, A and B -are the mirrors, C- the semi transparent mirror, and E-the screen. There are two paths from the (light) source S to the screen. One reflects off the semi-transparent mirror (beam splitter) at C, goes to the top mirror B and then reflects back, goes through the semi-transparent mirror, to the screen. The other

first goes through the semi-transparent mirror, to the mirror on the right A, reflects back to the semi-transparent mirror, then reflects from the semi-transparent mirror into the screen. If these two paths i.e. SCAE and SCBE differ by a whole number (including 0) of wavelength there is constructive interference. If they differ by a whole number and a half wavelength (e.g., $1/2, 3/2, 5/2, \dots$) there is destructive interference. This can be written as follows (Path difference) $\Delta S = 2(CB - CA) = m\lambda$ constructive interference $\Delta S = 2(CB - CA) = m\lambda/2$ destructive interference Where the wavelength of the light beam and 'm' is whole number. Note that we can't get such patterns if the phase difference between the two interfering beams is variable. In other words Δs_c is restricted by this condition (it occurs in case when the phase difference is constant). Experiment shows that the coherence length is related to the spectral width ΔW of the incident wave by the relation $\Delta s_c = c/\Delta w$. This observation may be explained as follows. A Wave emitted from a point source with the spectral width ΔW can be regarded as a superposition of many quasi-monochromatic components with frequencies w_n within the interval ΔW . The superposition results in wave trains of finite length $\Delta S_c = c\Delta t = \frac{c}{\Delta w}$ because the different components with slightly different frequencies w_n come out of phase during the time interval Δt and interfere destructively causing the total amplitude to decrease if the path difference ΔS in the Michelson interferometer becomes larger than ΔS_c , the split wave trains no longer overlap in the plane E. the coherence length ΔS_c of a light source becomes larger with decreasing spectral width ΔW . This shows that the less the spectral width the greater will be the coherence length. This is what is mainly observed in lasers. The arrangement shown above in the figure is Young's double slit interference experiment. It is used to determine the coherence volume i.e. a volume in which the interference phenomena

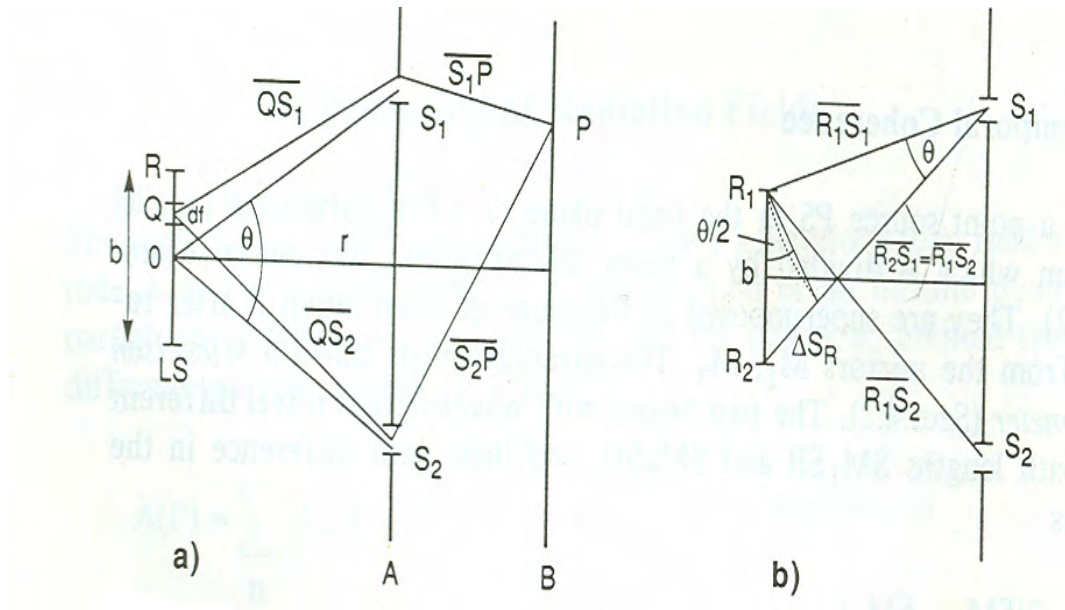


Figure 1.2: Young double slit

can be observed directly. The radiation is from an extended source LS of size b illuminates two slits S_1 and S_2 in the plane A a distance d apart. The total amplitude and phase at each of the two slits are obtained by superposition of all partial waves emitted from the different surface elements df of the source, taking in to account the different paths $df-S_1$ and $df-S_2$. The intensity at the point of observation P in the plane B depends on the path difference $S_1P - S_2P$ and on the phase difference $\Delta\Phi = (\Phi(S_1) - \Phi(S_2))$ of the total field amplitudes in S_1 and S_2 . If the different surface elements df of the source emit independently with random phase (thermal radiation source) the phase of the total amplitudes in S_1 and S_2 will also fluctuate randomly. However, this would not influence the intensity in p as long as the fluctuations occur in S_1 and S_2 synchronously, because then the phase difference $\Delta\phi$ would remain constant. In this case, the two slits form two coherent sources which generate

an interference pattern in the plane B. For radiation emitted from the central O of the light source, this proved to be true since the paths OS_1 and OS_2 are equal and all phase fluctuations in 0 arrive simultaneously in OS_1 and OS_2 . For all other points Q of the source, however; path difference $\Delta S_Q = QS_1 - QS_2$ exist which are largest for the edges R of the source. From Fig 1.2. b one can infer for $b \ll r$ the relation $\Delta S_R = R_1S_2 - R_1S_1 = R_2S_1 - R_1S_1 \approx b \sin(\frac{\theta}{2})$. For $\Delta SR > \frac{\lambda}{2}$ the phase difference of $\Delta\Phi$ the partial amplitudes in S_1 and S_2 exceeds Π . With random emission from the different surface elements df of the source, the time-average interference pattern in the plane B will be washed out. The condition for coherent illumination of S_1 and S_2 from a light with the dimension b is therefore $\Delta S = b \sin(\frac{\theta}{2}) < \frac{\lambda}{2}$ with $2b \sin(\frac{\theta}{2}) = \frac{d}{r}$ this condition can be written as $\frac{Bd}{r} < \lambda$ Extension of this coherence condition to two dimension yields for a source area $A_s = b^2$ the following condition for the maximum surface $A_c = d^2$ which can be illuminated coherently: $\frac{B^2 d^2}{r^2} \leq \lambda^2$ Since $d\Omega = \frac{d^2}{r^2}$ is the solid angel accepted by the illuminated surface $A_c = d^2$ this can be formulated as

$$A_s d\Omega \leq \lambda^2 \quad (1.2.5)$$

The source surface $A_s = b^2$ determines the maximum solid angel $d\Omega \leq \frac{\lambda^2}{A_s}$ inside which the field shows spatial coherence. Equation 1.2.5. reveals that radiation from a point source (spherical waves) is spatially coherent within the whole solid and angel $d\Omega = 4\Pi$ the coherence surfaces are spheres with the source in the center. Likewise, a plane wave Produced by a point source in the focus of a lens shows spatial coherence over the whole aperture confining the light beam. For given source dimension, the coherence surface $A_c = d^2$ increase with the square of the distance from the source. The argument above may be summarized as follows: the coherence surface S_c i.e., that

maximum area A_c which can be coherently illuminated at a distance r from an extended quasi-monochromatic light source with the area A_s meeting at a wavelength λ is determined by

$$s_c = \frac{\lambda^2 r^2}{A_s} \quad (1.2.6)$$

With the coherence length $\Delta s_c = \frac{c}{\Delta w}$ in the propagation direction of the radiation with the spectral width ΔW and the coherence surface $S_c = \frac{\lambda^2 r^2}{A_s}$ the coherence volume

$$V_c = S_c \Delta s_c \quad (1.2.7)$$

$$V_c = \frac{\lambda^2 r^2 c}{\Delta w A_s} \quad (1.2.8)$$

The less the spectral width the greater will be the coherence volume.

1.2.1 Coherence length for holography

Every laser has what is termed a coherence length. It is related to the length of the laser tube and the purity of the phase of light emitted and the wavelength itself. The more pure the light the greater the coherence length. That is, not just any kind of laser can be used in making a hologram. On the specification sheets of most quality lasers manufactured today you will see the term TEM (infinity). This means that the laser is operating in the lowest transverse mode, which is the most uniform across the beam and is preferred for holography. A laser intended for making holograms must ideally be lasing in just one longitudinal mode. Both of these qualifications, i.e. spatial coherence and longitudinal coherence, define the purity of the light. In twin beam holography it is extremely important to measure the paths of the reference beam and object beams(s) for even if you are using the prescribed laser for holography its coherence length is not infinite. The coherence length also places an upper limit on

the size, especially depth, of the object which can be holographed by setting definite bounds to the path difference of the reference and object beams. These concepts are subtle and can be quite difficult to understand so let me explain a little further. First of all, a laser ideally is emitting all of its light in one and absolutely only one wavelength with all of those wavelengths completely in phase from the point of exit to infinity. This would be wonderful, but unless you have a fifty mW or more laser with a special attachment called an etalon, your coherence length is probably around six to eight inches. This is the approximate length of an average 5 milliwatt, He-Ne laser. This means that once you separate your original beam and secondary beam, the path difference which they travel cannot exceed six inches. If the distance of the reference beam from the beam splitter to the hologram is 48 inches, then the distance of the object beam from the beam splitter to the object to the hologram must also be 48 inches. Then your available path difference can be utilized totally by your object. In a way this can be related to depth of field in photography, but in holography outside of that depth of six inches the object drops off into nothingness. In a way, you "focus" on your object by making sure the lengths of your object's beam(s) and reference beam are measured correctly. NOTE The coherence length is vitally affected by the type of laser used. Depending on the kind of laser you are working with you may have to adjust the length (the difference can be sizable). When in doubt check with the manufacturer. The light being emitted by lasers has what you might call a coherence curve. It is a bell shaped curve which shows, in distance from the exit point of the laser, where the wavelengths are most in phase. This is usually a constant integer and depends on the wavelength or substance which is lasing, the size of the laser as well as how purely it is emitted. This number, as how purely it is emitted.

This number, let's say eight inches remaining constant. At the peak of the curve, or every eight inches, the light is most in phase. you would make the path lengths of your beams multiples of twice the cavity length of your laser. In addition, the coherence function repeats itself. It is at maximum again at a distance of twice the mirror separation in the laser. It repeats itself. It is at maximum again at a distance of twice the mirror separation in the laser. It repeats itself every $2L$ distance. Before buying a laser for us in holography it is always wise to inquire about all the pertinent characteristics of its functions.

1.3 Diffraction

Diffraction occurs whenever a wavefront encounters an object. A diffraction grating is a structure with a repeating pattern. A simple example is a metal plate with slits cut at regular intervals. Light rays traveling through it are bent at an angle determined by θ , the wavelength of the light and d , the distance between the slits and is given by $\sin \theta = \frac{\lambda}{d}$.

1.3.1 Diffraction Grating

Grating in optics is a optical component with a surface covered by a regular pattern of parallel lines, typically with a distance between the lines comparable to the wave length of lights. Lights rays that pass through such as a surface are bent as a result of diffraction, related to the wave properties of light. This diffraction angles depends on the wave length of the light. For a given grating, light with a large wavelength generally has a large diffraction angle. More precisely, a single wavelength can simultaneously have multiple discrete diffraction angels, called **diffraction order** When

a beam is incident on a grating with an angle θ (measured from the normal of the grating), it is diffracted into several beams. The beam corresponding to direct transmission (or specular reflection) in the case of a reflection grating is called the **zero order**, and is denoted $m = 0$. The other orders correspond to diffraction angles which are represented by non-zero integers m . For a groove period d and an incident wavelength λ , the grating equation gives the value of the diffracted angle θ_m (in the order m)

$$d(\sin \theta_m(\lambda) + \sin \theta_i) = m\lambda \quad (1.3.1)$$

Note that 'm' can be positive or negative, resulting in diffraction orders on both sides of the zero order beams. Note also that there exist various conventions for choosing the sign of the angles, possibly resulting in different signs in the grating equation. When there is a need to separate light of different wavelengths with high resolution, then a diffraction grating is most often the tool of choice. This "super prism" aspect of the diffraction grating leads to applications for measuring atomic spectra in both laboratory instruments and telescopes. A large number of parallel closely spaced slits constitutes a diffraction grating. The condition for maximum intensity is the same as that for the double slit or multiple slit but with a large number of slits with the same intensity maximum is very sharp and narrow, providing the high resolution for spectroscopic applications. The peak intensities are also much higher for the grating than for the double slit. The main point to be stressed regarding diffraction gratings is the impact when light of a single wavelength like laser is incident. It is easily observable that when a light of single wavelength strikes a diffraction grating it is diffracted at different angles. This point is important in holographic reconstruction processes.

1.3.2 summary

A very simple hologram can be made by superimposing two plane waves from the same light source. One (the reference beam) hits the photographic plate normally and the other one (the object beam) hits the plate at an angle θ . The relative phase between the two beams varies across the photographic plate as $2\pi y = \sin\theta/\lambda$ where y is the distance along the photographic plate. The two beams interfere with one another to form an interference pattern. The relative phase changes by 2π at intervals of $d = \lambda/\sin\theta$ so the spacing of the interference fringes is given by d . Thus, the relative phase of object and reference beam is encoded as the maxima and minima of the fringe pattern. When the photographic plate is developed, the fringe pattern acts as a diffraction grating and when the reference beam is incident upon the photographic plate, it is partly diffracted into the same angle θ at which the original object beam was incident. Thus, the object beam has been re-constructed. The diffraction grating created by the two waves interfering has reconstructed the "object beam" and it is therefore a hologram as defined above. Holographic reconstruction process a slightly

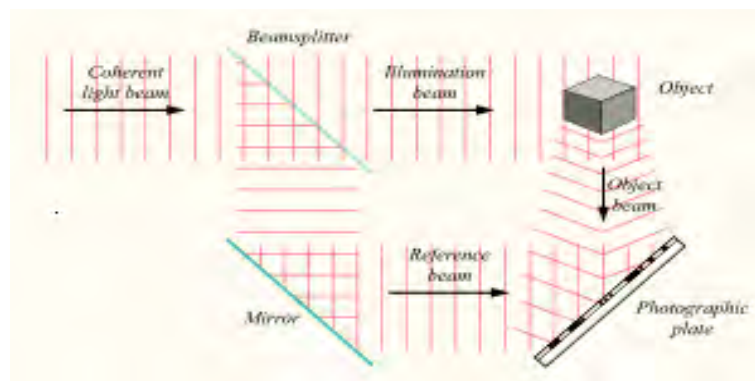


Figure 1.3: hologram recording

more complicated hologram can be made using a point source of light as object beam and a plane wave as reference beam to illuminate the photographic plate. An interference pattern is formed which in this case is in the form of curves of decreasing separation with increasing distance from the center. The photographic plate is developed giving a complicated pattern which can be considered to be made up of a diffraction pattern of varying spacing. When the plate is illuminated by the reference beam alone, it is diffracted by the grating into different angles which depend on the local spacing of the pattern on the plate. It can be shown that the net effect of this is to re-construct the object beam, so that it appears that light is coming from a point source behind the plate, even when the source has been removed. The light emerging from the photographic plate is identical to the light that emerged from the point source that used to be there. An observer looking into the plate from the other side will "see" a point source of light whether the original source of light is there or not. This sort of hologram is effectively a concave lens, since it "converts" a plane wavefront into a divergent wavefront. It will also increase the divergence of any wave which is incident on it in exactly the same way as a normal lens does. Its focal length is the distance between the point source and the plate. Complex objects For making a hologram of yourself, the laser beam is split in two by your image. One beam illuminates the object which then scatters your image onto the recording medium. The second (reference) beam illuminates the recording medium directly. According to diffraction theory, each point in the object acts as a point source of light. Each of these point sources interferes with the reference beam, giving rise to an interference pattern. The resulting pattern is the sum of a large number (strictly speaking, an infinite number) of point source + reference beam interference patterns. When the

object is no longer present, the hologram is illuminated by the reference beam. Each point source diffraction grating will diffract part of the reference beam to re-construct the wavefront from its point source. These individual wavefronts add together to re-construct the whole of the object beam. The viewer perceives a wavefront which is identical to the wavefront scattered by the object, so that it appears to him or her that the object is still in place. This image is known as a "virtual" image as it is generated even though the object is no longer there. This explains, albeit in somewhat simple terms, how transmission holograms work. Other holograms, such as rainbow and Denisyuk holograms, are more complex but have same principles. At this point,

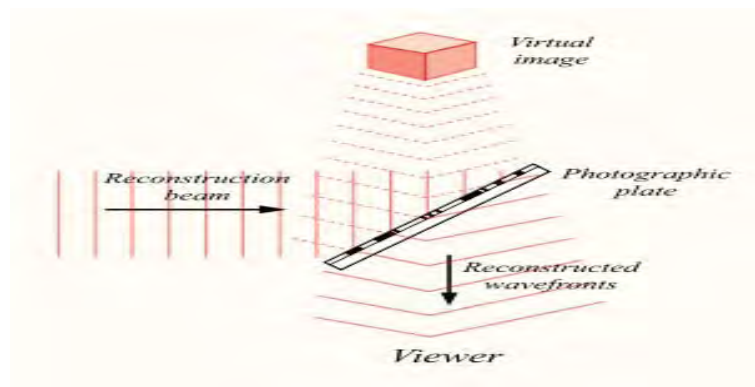


Figure 1.4: holograph reconstructing

however, we feel you have been offered enough of the basic theory of holography and now we will begin applying all of this to the construction of a lab and construction of holograms. Naturally as your practical experience grows you will be able to absorb more theory.

Chapter 2

LASER

2.1 Introduction To Laser And Laser Light

The understanding of the simulated emission of light, or how a laser works will greatly aid in conceptualizing the holographic process. Because with out the laser, the unique three dimensional imaging characteristics and light phase recreation properties of holography would not have been possible. As laser is a light amplifier, with very special characteristic and its explanation depends on the theory of radiation.

The laser is important to get a clear interference pattern, for a better understanding of holography. **Laser** is an acronym for light amplification by stimulated emission of radiation. In this chapter we will describe some basic facts about laser , properties of laser and its operations.

2.1.1 Laser

Now that we know a little something about light in general, we may consider the light source needed to perform holography: the laser, which stands for light amplification by stimulated emission of radiation. The understanding of the stimulated emission

of light, or how a laser works, will greatly aid in conceptualizing the holographic process. Without the laser, the unique three dimensional imaging characteristics and light phase recreation properties of holography would not exist as we know them today. Two years after the advent of the continuous wave laser, *c.*1959 – 1960, Leith and Upatnieks (at the University of Michigan) reproduced Gabor's 1947 experiments with the laser, and launched modern holography. The laser was designed and made to work after two very useful theories had come on the scene. One is Niels Bohr's atomic theory and the other is the Quantum Theory. Niels Bohr, a Danish physicist, in the year 1913, proposed a model of the relationship between the electron and nucleus of the hydrogen atom. Bohr utilized the newly developed Quantum Theory in proposing that an electron circling the nucleus can assume certain discrete quantized levels of energy. In the lowest level, called the ground state, the electron is circling closest to the nucleus. However, if the atom is exposed to an outside source of energy the electron can be raised to a higher energy level, or an excited state, which is characterized by the electron curving a circle of greater circumference around the nucleus. It is important to note that the electron can't go just anywhere when it is excited but has to assume certain levels. Also, not just any energy would suffice in raising the electron's orbit. The energy must be equal to the energy difference between the ground state and the excited state the electron assumes. The frequency is the energy difference divided by "h" or Planck's constant i.e

$$\frac{E_e - E_g}{h} = \nu \quad (2.1.1)$$

where E_e -the excited state, E_g - the ground state energy, There are actually a number of different energy levels which the electron may assume but that is not essential to this explanation of how a laser works. Energy is radiated in discrete packages, and these

packages interact only on a very selective basis. There are two important reasons why lasers work. The laser depends on the very special emission characteristics of certain atoms whose electrons have been raised to the excited state. When the electron falls back down to its lower energy level (as all electrons eventually do), it in turn emits a package of electromagnetic or radiant energy which precisely equals the energy difference between the two levels, ground state and excited state. In a sense, what goes in comes out. This fact alone doesn't suffice in making a substance lase, for if too many electrons are in the ground state, the energy input would merely be absorbed by the electrons in the ground state which then might spontaneously emit a quantum of the correct size sometime in the future and that would be the end of that. We don't want to have an atom emitting its photon at just any old time, so we stimulate the atom to emit its energy package when we want it to. A package which would not be absorbed by another atom in ground state but would stimulate an atom already in an excited state to emit its own photon. In order to maintain the stimulated emission of photons which produce laser light, you must initiate and maintain a population inversion. In lasers, electronic principles are applied to the visible portion of the spectrum. In electronics, oscillation is achieved with feedback around an amplifier. The feedback circuit determines the frequency of oscillation. In a laser, the tube of excited atoms is the amplifier. The mirror or resonator is the feedback circuit. Oscillation occurs at those wavelengths where the product of gain equals the loss, for a round trip, say starting from one mirror and coming back again. The gain of a laser is determined by population inversion, or having many more excited electrons, than electrons in the ground state i.e. electrons at their lowest energy level. The helium-neon laser, which is probably the most common laser in use today (due

to its relatively low cost) is the laser we used most. The laser tube itself contains approximately 10percent helium and 90percent neon. Of these two inert gases, neon is the active agent in the lasing process. We could term helium the catalyst insofar as it facilitates the energy input to the neon. Before more energy is purposefully forced in the system, there is some action among the atoms and molecules comprising the gases. Some although very, very few of the electrons are already in the excited state, or upper energy levels and when they fall down, as they all tend to do, they emit a photon, only to be quickly absorbed. The gain or loss of a photon or quantum of energy which is defined by a change in electron orbit takes place on the order of 10^{-15} to the power of 15 seconds or 100 millionths of a second. You might ask how even some of the atoms might have electrons in the excited state if there's no energy input, i.e., before the laser is switched on. The answer is purely statistical. For example, if you have a church filled to capacity for a Sunday morning mass, say 250 people, someone has got to cough or sneeze during the sermon. If you take the number of times some two or three people cough and compare that with the amount of times everyone in the church inhaled and exhaled without occasion, it would give you some idea of the situation in the laser tube before excitation. A few atoms are excited and then fall back to emit energy. This energy in turn goes off spontaneously to another atom whose electron almost certainly is in the ground state. The photon is absorbed. This is the key to the laser. If we have enough atoms with electrons in the excited state, the photon not only would not be absorbed, but when it did reach another excited atom it would induce it to cough up its own photon. We go from one, to two, to four, to eight, to sixteen photons very rapidly. We have achieved population inversion, i.e., many more electrons are in the excited state than in the ground state. Remember

we are considering only the helium-neon laser. It is the most economical laser and probably the one you would be using. There are other lasers such as the argon-ion laser which is able to lase in both blue and green, and better yet a mixed gas argon-krypton ion laser which is able to lase in blue, green and red. The problem is that the prices of these lasers are very expensive. There is also the pulse ruby laser which allows you to make holograms of animate objects. In the ruby laser chromium ions locked in a sapphire host are the sources of stimulated emission. The chromium atoms are excited by a light flash from a special flashlamp. Let's backtrack slightly and talk briefly about the job helium performs before we go on to the more mechanical aspects of laser operation. It so happens that helium has a metastable (or long lived) energy level that coincides quite well with one of the energy levels of neon which we need to obtain for lasing action to commence. Scientists discovered that it is much easier to raise helium to the excited state and let it transfer the correct energy packets to the neon when they meet inside the tube (which is at the correct pressure to assure their close acquaintance). So the helium is used as sort of a messenger, or filter, if you will, to store the correct high energy input origination from the laser power supply for the neon. Although the neon is the active ingredient in the laser, the helium greatly facilitates the process. Virtually all we have so far, then, is a glorified light tube such as you might find lighting the streets of any late night hot spot worth its salt. The difference from this light tube stage of development to the functioning laser is essentially more of a mechanical characteristic, i.e., the precise geometrical relationship of its optical components.

The photons are emitted from the atoms inside the tube in all different directions. However, a very small percentage, around 2 percent, begin traveling in a horizontal

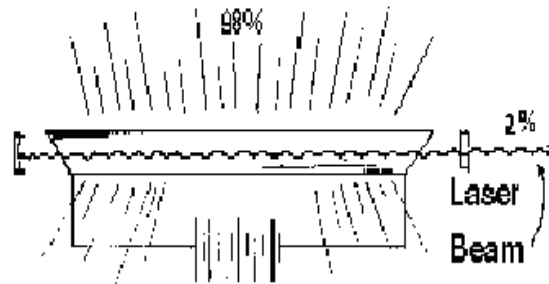


Figure 2.1: laser

direction within the tube. They naturally stimulate already excited atoms along the way to emit their photons in the same direction. This would actually mean nothing if we did not then place mirrors at both ends of the light tube in order to induce the light to start moving back and forth along the horizontal line of the tube. Eventually this induces a large number of photons to travel in the same direction and one of the mirrors is only partially reflective which lets the light leak out. Now we should be able to discuss the properties of the laser with this further explanation: The source of the light is the energy given off when an atom's electron falls back down toward the ground state. There is only one type of atom taking part in the actual coherent, laser light giving process; therefore, according to the law of Quantum Mechanics the energy given off by identical energy shifts in each atom must be exactly the same. In other words each photon has precisely the same amount of energy. It will also have the same frequency and wavelength, and will be coherent light. It is the mirror set-up, sometimes called the resonant cavity, which induces this fully saturated, monochromatic light to exit the tube in a straight, narrow beam, for then

not only do they contain the same amount of energy in stimulated emission, but the photons travel in the same direction. Actually the precise wavelength emitted by a laser is determined by the mirror separation: The lasing transition gives a band of wavelengths over which the laser can emit. The diameter of the exit beam varies with bore of the tube but most helium neon beams are around 1.5mm diameter at exit and do not spread nearly as quickly as incoherent light would. Thus laser light is coherent because it is radiated by a homogenous collection of atoms under precisely the same conditions. The mirrors at both ends make the small percentage of photons that hit the mirrors return in a straight line. This develops a cascade of light along the horizontal line of the tube. If you were to remove the laser casing you would see the same monochromatic, saturated light but the straight beam, so distinctive of laser light, would only be emitted from the end with the partially coated mirror.

2.2 Basic Design Of Laser

A basic laser system (see figure 2.2) has two mirrors that are placed parallel to each other to form an optical resonator so that light can be transmitted back and forth between the mirrors along the optical axis.

Between the mirrors is the active medium that can amplify the light by stimulated emission. Under certain pumping mechanism, the active medium can be excited from lower energy state to upper energy state, population inversion happens. Stimulated emissions give out photons in all directions at first. But the photons are transmitted through the system, only photons whose directions are along the optical axis can last, photons in other directions will either be scattered or absorbed. Soon almost all the photons in the system are oscillating in the optical axis direction. One incident

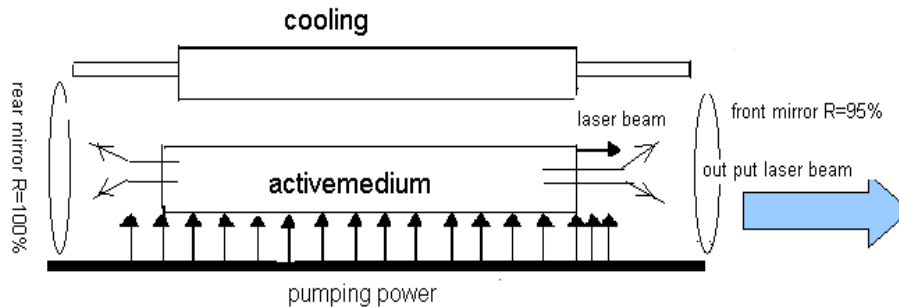


Figure 2.2: The basic laser system

photon can become two photons after every stimulated emission, so under proper conditions, light density is amplified. Usually one of the mirrors is nearly totally reflecting. Another is partially reflecting, the partially reflecting mirror will transmit laser light either in continuous wave (CW) or in pulsed mode. The basic elements of a laser are;

1. The active medium
2. The energy pump
3. The optical resonator

1 The active medium (gain medium) is a medium which transfers external energy in to the laser beam. It is a material of controlled purity size and shape, which

amplifies the beam by the quantum mechanical process of stimulated emission. It is energized by external source.

- 2 The energy pump is the external energy source. The pumping mechanism may be electrical, optical, chemical etc.
- 3 The optical resonator (cavity) consists of two reflective surfaces so that each photon passes through the gain medium more than once before it is emitted from the out put aperture (or lost of diffraction or absorption).

2.2.1 Types Of Laser

Lasers can be divided into gas, solid state and liquid lasers according to the active medium used for laser action.

Gas lasers: Gas Lasers can be further divided into neutral atom, ion and molecular lasers , whose lasing mediums are neutral atoms, ions or gas molecules respectively. Helium-neon (He-Ne) laser is a kind of neutral atom gas laser, the common wavelength of a He-Ne laser is 632.8 nm, it is tunable from infrared to various visible light frequencies. Carbon dioxide laser is a typical molecular gas laser, it emits laser, it emits laser light at a wavelength of $10.6\mu m$, its beam power ranges from several watts to 25kw or even to 100 kw, so CO_2 laser is widely used in laser machining.

solid lasers: In solid state lasers, ions are suspended in crystalline matrix to generate laser light. The ions emit electrons when excited; the crystalline matrix spread the energy among the ions. The first solid state laser is ruby laser, but it is no longer used because of its low efficiency. Two common solid state lasers are

- Nd: YAG lasers

- Nd: glass lasers,

These structures are very similar. Both use krypton or xenon flash lamps for optical pumping. Semiconductor lasers use pn junctions as active medium. They can operate by relatively low power.

Liquid Lasers: Liquid Lasers use large organic dye molecules as the active lasing medium. These lasers can lase in a wide frequency range, i.e. they are frequency tunable. The spectral range of dyes covers infrared, visible and ultraviolet light. Pumping is by another pulsed (continuous laser), or by pulsed lamp. These lasers are used in spectroscopic investigation and photochemical experiments.

2.3 Properties Of Laser Beam

Monochromatic: This property is due to the following two factors,

- First, only on EM wave of frequency $\nu_o = (E_2 - E_1)/h$ can be amplified, ν_o has a certain range which is called line width, this line width is decided by broadening mechanisms such as homogenous or inhomogeneous broadening.
- Second, the laser cavity forms a resonant system; oscillation can occur only at the resonance frequencies of this cavity. This leads to the further narrowing of the laser line width, the narrowing can be as large as 10 orders of magnitude. So laser light is usually very pure in wavelength and has red color, we can say that it has the property of monochromatic.

Coherence: Laser light is highly coherent, and this property has been widely used in measurement, holography, and etc.

Divergence and Directionality:

Laser beam is highly directional, which implies laser light is of very small divergence. This is a direct consequence of the fact that laser beam comes from the resonant cavity, and only waves propagating along the axis of the resonator can be sustained in the cavity. The directionality is described by the light beam divergence angle. **Brightness:** Brightness is one of the properties of laser, the brightness of a light source is determined by the power emitted per unit surface area per unit solid angle. This quantity is relatively very large for laser beam.

2.4 Application Of Laser

Some of the application of lasers are:

- Interferometry holography, spectroscopy bar code scanning, alignment, optical demonstration.
- Scientific research
- Metal processing (cutting, welding etc)
- Printing and type setting applications.
- Telecommunications
- Atmospheric research
- Material processing
- Medical application(surgery).

Chapter 3

HOLOGRAPHY

As in the case of many classical research result finding holography is the consequence of mankind struggle on nature to make his day to day life activities simple and easy .It is a phenomena which facilitate by the discovery of laser light,has many application in different areas and still a topic of research and investigation for many scientists.

3.1 A Brief Historical Background Of Holography

The theory and improvement marks its starting point at 1941 when British native Hungary scientist Dennis Gabour developed the theory of holography while working to improve the resolution of an electron microscope ,he related the the holography from Greek word *hollo* meaning whole or complete and *grama* meaning message. The effort of further development in the field was tackled during the next decade because of lack of really coherent light source. Gabour's holography was limited to film transparencies using mercury arc lamp as light source , the image formed are not as clear as holographic images to day his hologram contained distortion and extraneous twin image . The barrier was overcomes in 1960 by Russian scientists ,N.Bassov and A.Prochov and American scientist Charles Towins with the invention

of laser whose pure intense light was ideal for making holograms. In that year the pulsed ruby laser was developed by Dr. T.h Miammthis. This laser system (unlike the cw laser normally used in holography) emits a very powerful burst of light that lasts only a few nanoseconds , it effectively freezes movement and makes it is possible to produces hologram of high speed events such as a bullet in-flight and of living objects . The first hologram of a person was made in 1967 paving the way for a specialized application of holographic portraiture. In 1962 Emmett Leith and Juris Upatneiks of the University of Michigan recognized from their work in side reading radar . That holography could be used as a 3-dimension visual medium in 1962 .They read Gabour paper and simple out of curiosity decided to duplicate Gabour's technique using the laser and an off axis technique borrowed from their work in the development of side reading radar .

The result was the first laser transmission hologram of 3D objects (a toy train and bird) . These transmission hologram produced images with clarify and realistic depth; but they required laser light to view the holographic image. Their pioneering work led to standardization of the equipment used to make holograms ,to day thousands of laboratories and studies posses the necessary equipment such as a continuous wave laser optical devices (lens, mirrors and beam splitters) for directing laser light a film holder and an isolation table on which exposures are made . Stability is absolutely essential because movement as small as a quarter wave length of light during exposures of a few minutes or even seconds can completely spoil a hologram .The basic off axis technique the Leith and Upthnieks developed is still the staple of hologram methodology. Also in 1962 Dr .yuri N.Denisyuk from Russian combined holography with 1908 Nobel laureate Gabriel Lipmanns work in nature color photography, Denisyuks

approaches produced a white light reflecting hologram which for the first time could be viewed in light from an ordinary incandescent light bulb. Another major advances in displaying holography occurred in 1968 when Dr. Stephen a.Benton invented white transmission hologram while researching holographic television at Polaroid research laboratories. This type of hologram can be viewed in ordinary white light creating a rainbow image from the seven colors which make up white light . The depth and brilliance of the image and its rainbow spectrum seen attracted artists who adapted this technique to their work and brought holography further into public awareness. After this time there were different effects on investigations of holography by different countries researchers of the world which is difficult to write all at once. Any way an increased their technical knowledge of the discipline and now contribute to the technological as well as the creative process the art form has become international with major exhibitions being held through out the world .

3.2 Holography

Holography is a process of 3-Dimensional image formation, in which the image is captured not as an image used on film, but as an interference pattern on the film. Since the presence of coherent light is necessary condition to set a clear interference pattern, the coherent light from laser is used for a best 3-D image formation (Holography). The coherent light from the laser is split in two to beams, namely **object beam** and **reference beam**, the beam from the laser source (after splitting)and scattered by the object to the film,and the beam from laser source (after splitting)to the film respectively. The light from the illuminated object and the reference beam form an interference pattern. This pattern known as **hologram** contains information

(records phase as well as amplitude) about the object which can then be viewed as a three dimensional image. However there are different kinds of holograms, the basic explanation for the 3-D image formation is almost common for all of them which is explained as follows:- Whenever two waves of equal frequency waves interfere at a distance, we have the well-known Youngs double slit pattern. The greater the separation between the sources, the higher the spatial frequency, in the pattern i.e the greater the number of fringes per meter, if photographic film is used to record this pattern, the result is a pattern of lines that can be used as a diffraction grating. The higher the spatial frequency in the grating the greater will be the angle of light diffracted. If the two beams of light interfering on the film make an angle greater than 45° with each other, the spatial frequency will be so high that when light is diffracted from this grating, there will only be room for the first order to come out, now let us apply this for the interference of object beam and reference beam. Take an object, whose depth is less than the coherence length $(\Delta)S_c$ of the laser, which is responsible for the object beam, each point on the object scattering laser light fall onto the film can be considered as an independent point source forming a set of lines on any elementary area of the film and creating a grating locally. Simultaneously all points on the object's scatter light on to any given elementary area from different directions. Thus each area performs a superposition of all the patterns formed between the direct beam and all the point sources. The finish hologram then, is a summation of many simple patterns , resulting in highly complex pattern. When a direct beam is used to illuminate a hologram, each elementary grating diffracts light recreating a point source that represents a point on the object. Note if the path difference between reference beam and object beam is greater than the coherence length, the

interference can't be observed clearly. A laser ideally is emitting all of its light in one and absolutely only one wavelength with all of those wavelengths completely in phase from the point of exit to infinity, but in reality this is limited in a few lengths for He-Ne laser around six to eight inches [15 – 20cm] . The well known method of image formation is photograph , then its comparison with hologram is very important to understand holography. One will be able to understand the very important difference between holography and photography if we discuss simply what happens in photographic process and what happens in holographic process. You will be able to understand the very important difference between holography and photography if we discuss simply what happens when you take a photograph and what happens when you make a hologram. A photograph is basically the recording of the differing intensities of the light reflected by the object and imaged by a lens. The light is incoherent, therefore, there are many different wavelengths of light reflecting from the object and even the light of the same wavelength is out of phase. Your emulsion will react to the light image focused by the lens and the chemical change of the silver halide molecules will result from the photon bombardment. There is a point to point correspondence between the object and the emulsion. By this we mean that a point or collection of points which reflects light on your object, for example a white hat, would be a source of more light to be focused by your lens than a black hat which could absorb rather than reflect light. The white object would expose more silver halide and after the development procedure, when you print your negative and it will naturally be lighter in the positive. Any object to be recorded can be thought of as the sum of billions of points on the object which are reflecting more or less light. The lens of the camera focuses each object point to a corresponding point on the film and there it exposes a

proportional amount of silver halide. Thus, your record is of the intensity differences on the object which form a pattern that one may ultimately recognize as the object photographed, in holography we are working with light waves and with, most likely, a silver halide film, yet, beyond that it is very difficult to compare the two.

As you well know by now the light sources are vastly different. The sun or common light bulbs give off light of all different wavelengths. The laser emits a single wavelength coherent light. If we were to simply illuminate our object with laser light and take a photograph, we would still only be recording the different light intensities of the object; we would not have captured any information about the phase of the light waves after bouncing off the object. How can we capture this vital information about phase? We need a standard or reference. In the same way that a surveyor needs a reference point in order to make his measurements, we need a standard or a reference source in order to record the phase difference of the light waves and thus capture the information which supplies the vital dimensions and depth, to the holographic presentation. This standard we call a reference beam and it is supplied by the laser light itself. The reference light is emitted in what we call a plane wave. By enlisting the aid of a beam splitter we are able to form two beams. The reference beam is allowed to hit the film directly. It might be spread with a lens and aimed at the film by a mirror, but for all practical purposes this does not affect the light waves. The other beam which we will refer to as the object or scene beam is also usually spread by a lens and guided by a mirror but it is directed at the object being holographed. Up until instant in time that the object beam strikes the object, it too is a plane wave. As soon as it hits the object it is changed, or modulated according to the physical characteristics and dimensions of the object. So that the light which

ultimately reaches the film plane after being reflected by the object now deviates in intensity and phase from .The virtually unhampered reference beam. That difference is a function of the object. What once began as a plane wave is now bouncing off the object in a complex wave front which consists of the summation of the multitude of infinitesimal object points reflecting light. Using a laser in order to have this added information about the object would do us no good if the reference and object beams were not allowed to interfere at the film plane. The simplest interference that could take place on the film would be between the reference beam and the object beam but with no object at all. So that actually you have simply two plane waves coming from different directions and interfering on the film. Obviously in this case, it does not matter which you call the reference or object beam for neither carries any information about an object and yet something very definitely is recorded. If we get a good understanding of this, the simplest case, it will be easier to understand as we move on to more complex situations. The two beams are interfering with each other as they pass through one another. The crest of one plane wave meets the crest of

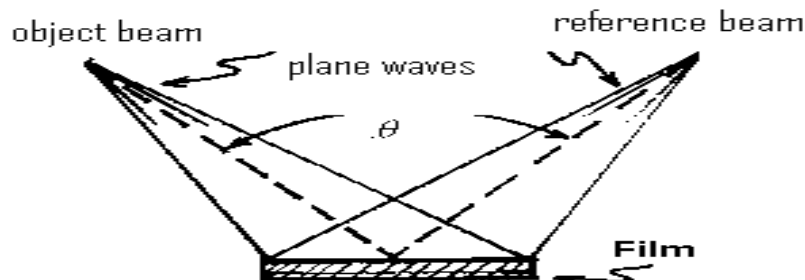


Figure 3.1: Interference phenomena

another, or perhaps the crest meets a trough. This is reminiscent of the Thomas Young experiment described earlier but with much more coherent light. When a crest meets a crest, it gives constructive interference and when a crest meets a trough, it gives destructive interference. Naturally where crest and crest meet there is more energy present and more of the atoms in the silver halide are affected or 'Exposed' than at a point on the film where a trough and crest meet. The accumulation of these points sets up a very fine stationary pattern or grating throughout space. The scheme of the pattern is a function of the wavelength of light, but more importantly, the angle difference between the two plane waves. We will get back to this point when we talk about the different types of holograms. It is important to remember that the direction of the light, phase of the light, etc, is preserved and coded in the emulsion by the very process of reference and object beam interference. So that if you were to shine number one beam back through the plate at the same angle you had in construction of the hologram, you would reconstruct the image of number two beam, and vice versa. The very fine pattern which the emulsion assumes is a recording of the wave fronts as they interfere in the emulsion. It is definitely not a direct point to point recording of the image of the object but rather a recording of the interference between the coherent light that hit the object and that which did not. We know that light, traveling in wave form, can be bent or diffracted along its path of travel. One way to bend light is by the use of a lens. You may consider a hologram a very complex lens, it is bending and forming part of the light of the reference beam, which is used for reconstructing the image, into the wave fronts of the original object, so that you may perceive the object as if it were really there. All the infinitesimal little points that reflected light which interfered with the reference beam on the film are

neatly focused to their respective positions in three dimensional space. In most cases, the object will reconstruct its original size, regardless of the size of the plate, and the same distance from the film that it was when the hologram was made. The reference reconstruction beam will be focused by the complex hologram lens to that the front of the object appears closer, the back further away, and all the points in between are filled in accordingly. This might sound like a point to point correspondence very much like photography. However, there is a very special difference which makes holograms so wonderful.

3.3 Kinds Of Holograms

There are different types of holograms . It is important to learn the basic differences between the various types and what terms are used in referring to them so that we will understand immediately what someone means if they say, for example, they have just made a reflection hologram or transmission hologram or in line hologram. Holograms can differ in the way in which they are produced and they can incorporate and store the information for playback. The latter difference is the simplest to explain so we'll begin with that. Under normal conditions we will be using a silver halide type film so we will talk about that specific case. The holographic information is coded in the emulsion according to the localized microscopic differences in the absorption of light or by the amount of silver halide converted to silver atoms during exposure and development. This is referred to as an absorption hologram. The absorption pattern on the film corresponds with the amount of light incident on the plate during exposure. If that same hologram is put through a bleaching process it will then be termed a phase hologram. The absorption index by changing the different residues

of silver to corresponding thickness of transparent substance. The hologram is then played back by the refraction of the reference beam dictated by changes of refraction in the emulsion. In a phase hologram the reference beam is phase modulated in order to reconstruct the wavefronts of the original objects. In absorption holograms the reference beam is diffracted by the small patterns of exposed emulsion in the form of silver residue.

Many holographers bleach all of their holograms because phase holograms absorb less valuable reconstructing laser light than the absorption type and thus create a brighter image. However, some holographers do not bleach regularly, especially if they have made a perfect exposure in their original hologram. This is due to the fact that there is a slight loss of resolution along with the gain in brightness. Also, a poor bleaching technique increases the amount of noise and can greatly reduce the resolution. The source of the controversy, if any, is merely personal taste. It is important to remember that the term absorption or phase hologram has nothing to do with the way the hologram was exposed but, in the case of silver halide emulsion, refers only to a bleaching process which follows exposure and development, (although you may alter your development process if you know in advance you are going to bleach). The following different types of holograms have special terms because they are actually constructed using different beam arrangements. The inherent difference between holograms has caused scientists and holographers to develop special terms or adjectives for them. In the construction stage the difference is usually nothing more than the beam and object beam, as they interfere on the film. This angle difference can produce very pronounced differences between holograms in the playback stage. For example, a plane transmission hologram has to be reconstructed with laser light

or a specially filtered light which approaches coherency in order for the reconstructed image to be crisp. A white light reflection hologram can in comparison be viewed quite clearly with sunlight or under ordinary incandescent light sources. Very simply, as the angle difference between reference and object beam increases, the tiny patterns in the emulsion exposed by the crest-crest interference of light waves are set up closer and closer together. The first hologram ever made by Dennis Gabor, in 1947, was an in-line, plane, transmission type. Remember at this time the laser was still yet to be developed, so Gabor had to make due with the quasi-coherent light gained by squeezing light from a mercury vapor lamp through a pinhole and then color filtering it (he used the 0.546 micron mercury green line). In-line means that the reference beam and object beam are coming from the same direction or are the same beam. Gabor had to do this in order to maintain the little coherency he had gained. All in-line holograms are also single beam set-ups. The same beam acts both as reference and object beam. This was made possible by using a transparency as the object. The light which went through the transparency before reaching the plate was modulated by the transparency, the light which went through it and was not effected by the transparency was the reference beam. The diffracted light and reference light interfered on the emulsion of the hologram and thus fulfilled one basic requirement for the construction of a hologram. When the reference beam was later shown back through the hologram at the same angle relationship it had with the plate in the reconstruction stage an image appeared. A poor image due to the lack of coherent light, but worse still the reference beam shone directly into the viewers eye, thus greatly compromising the viewing of the reconstructed object. Although it was a poor image it was there in all its dimensionality. A new medium had been born, alas,

a little prematurely and in 1948, was placed on the shelf until the advent of the laser. Please note that through his experiments Gabor proved that an interference pattern carries all the information about the original object and that from the interference pattern one can reconstruct the object.

Transmission Holograms As I mentioned above in order to playback a hologram the reference beam must be shine back through the hologram at the same angle relationship as it had in construction. This is where the term transmission hologram arises. Transmission merely means that the reference beam must be transmitted through the hologram in order for the image to be reconstructed. In 1962 Leith and Upatnieks at the University of Michigan removed Gabor's brain child from the shelf and gave holography its rebirth. Like Gabor they did their early experiments with a filtered mercury arc lamp. Leith and Upatnieks invented the off-axis reference beam with all its great advantages which they did not even appreciate at the time. After the development of the continuous wave gas laser in 1960 by Ali Javan et al. Leith and Upatnieks started using the laser and discovered the three dimensionality of the images. They performed these experiments as an adjunct to their work in side-looking microwave radar. They independently discovered off-axis holography only to find that Gabor had proposed holography 12-14 years earlier. The term off-axis means that the reference beam and object beam are not coming from the same direction. Naturally in order to perform this feat we must have two different beams, thus the term twin beam. Because the laser gives a homogenous beam of coherent light we can extract a beam from the original beam as I mentioned earlier. This is done with the aid of a beam splitter, which could be nothing more than a piece of optical glass. A part of the original beam goes through the glass and a part is reflected at the same angle as

its incident. This allows one to bring in the reference beam from an infinite number of angles in relation to the object directed beam, thus avoiding the inconvenience in playback of having to look directly in the reference beam as with the in-line, transmission hologram.

Plane and Volume Holograms This is a good time to point out the differences between a plane hologram and a volume hologram. As the angle difference between the object beam (or the wavefronts bouncing off the object) and the reference beam changes, so does the spacing of the patterns in the emulsion. As long as the angle difference remains less than 90 degrees the hologram is called a **plane hologram**. Plane meaning that the holographic information is primarily contained in the two-dimensional plane of the emulsion. Although the emulsion does have a thickness, usually around seven microns or 7/millionths of a meter, the spacing between fringes is large enough, when the angle is under 90 degrees, for us to imagine that the depth of the emulsion isn't really being utilized in the recording of the hologram. At 90 degrees, which is really a convenient but arbitrary point, the angle is great enough and fringe spacing has become small enough for us to say that the recording process is taking place throughout the volume of thickness of the emulsion. A point to remember is that although there are different thicknesses of emulsion put on celluloid or glass plates seven microns is an average. One can use the same emulsion say seven microns thick, and make both plane and volume holograms depending on the angle difference between reference and object beam. Thus if you imagine your film in a fixed plane and your object in a stationary position, as you rotate the incidence angle of the reference beam, you can determine whether you are making a plane or volume holograms. If your angle is under 90 degrees it's plane, from 90 degrees - 180 degrees it's volume.

Naturally, past 180 degrees you merely begin coming back the other way, through the volume to the plane and when finally you reach 360 degrees you are back at the in-line, plane, transmission hologram . A very important point for differentiation occurs as the reference beam swings around its arc of possible positions. In a plane transmission hologram the reference beam is hitting the film from the same side as the object beam. In a volume reflection hologram the reference beam has made an arc clear around so that it hits the film from the opposite side as the modulated object beam. When 180 degrees difference is reached you are the constructing an in-line, volume, reflection hologram. A transmission type hologram means that the reference beam must be transmitted through the hologram, in order to decode the interference patterns and render the reconstructed image. The light which is used for playback must be coherent or semi-coherent or the image will not be sharp. If a non-coherent source, such as the light from a common, unfiltered slide projector is used, then the hologram will diffract all the different wavelengths. The interference pattern or grating etched in the emulsion is not particular as to which wavelengths it bends or focuses; therefore, you end up with an unclear overlapping spectrum of colors which somewhat resemble your object. A hologram will playback just as well with laser light of a different color or wavelength than the light with which it was made. However, the object will appear to be of a different size and/or distance from the plate. For example, a hologram of an object made with neon or red light will playback that object smaller or seemingly further away if a blue color laser is used. This is because the grating will bend the blue or shorter light less severely than the red with which it was made and with which it is meant to be decoded.

Reflection Hologram Unlike a plane hologram, sometimes called a thin hologram, which requires a coherent or highly filtered playback source, a reflection, or thick, hologram can be viewed very satisfactorily in white light or light which contains many different wavelengths. The one requisite is that the light be from a point source and be a somewhat straight line, such as a slide projector light or penlight, or the sun on a clear day. The reflection hologram can do this because in a way it acts as its own filter. In a reflection hologram the fringes are packed so closely together that they constitute layers throughout the thickness of the emulsion. The spacing between fringes remains constant. If "d" or the distance between fringe one and two is two microns for example, then the distance between the remaining layers of fringes will also be two microns. This distance is a function of the wavelength of light used in constructing the hologram and also the angle difference between reference and object beam. This layered affair allows the reflection hologram to absorb, or not reflect, any of the colors or wavelengths of light which are not the correct length. The wavelength which matches the fringe spacing will be reflected: the crests of the wavelengths which are too short or too long will eventually miss one of the planes and be absorbed into the darkness of the emulsion. In a reflection type hologram the playback light or reconstruction beam comes from the same side of the hologram as the viewer. Some parts of the incident light are reflected, some are not, depending on the interference pattern. If the hologram was made correctly the result should be a visible three dimensional image. As I mentioned before in the transmission type the reconstruction beam must pass through the hologram and come towards the viewer from the opposite side of the hologram while in the reflection type the playback source comes from the same side of the hologram as the viewer.

Incidentally just as very few transmission holograms are made in-line or 0 degrees so are very few reflection holograms made inline or else you would have to hold your point light source in your teeth or perhaps invest in a miner's cap. Most reflection holograms are made at a less severe angle, perhaps 160 degrees, so that the light can come in at an angle without being blocked by the person who is trying to see the hologram. The image produced by the hologram can either appear to be in front of the holographic plate or film, or behind the film. In the former case it is called a real image (projection) and the latter a virtual image. If you imagine your position as viewer to be constant then you can easily determine whether an image is real or virtual. If the image appears between you and the hologram it is a real image, if the hologram is between you and the apparent object then it is called a virtual image. In general it is easier to view a virtual image because you can see through the hologram as if it were a window.

Multiplex Hologram In addition to the previously mentioned types of holograms commonly made today there is the multiplex hologram and the image hologram. These types of holograms are being used more commonly today. Very simply the multiplex hologram is the holographic storage of photographic information. In the first stage a series of photographs or a certain amount of motion picture footage of the subject is exposed. The number of stills or frames taken depends on how much of an angle of view you want of the subject in your finished hologram. For example if you want a 360 degree view of the subject you might expose 3 frames per degree of movement around the subject (usually the camera remains stationary and subject rotates) this will result in the exposure of 1080 frames. When your film is developed

you proceed to the holographic lab and (using a laser) make a series of "slit" holograms using each frame of film as a subject for each slit of holographic film. The slits are usually about one millimeter wide and are packed so closely that there is no "dead space" in between. Also the hologram is bleached so that the strips disappear. Usually a multiplex hologram yields horizontal not vertical parallax. This is because the camera usually moves around (or the subject moves around in front of the camera) and doesn't usually pass over the subject. Also, psychologically, horizontal parallax is much more desirable and the lack of horizontal parallax, to humans, is much more noticeable than the lack of vertical parallax. The multiplex hologram is usually, though not always, made on flexible film coated with the same holographic emulsion as the plates. The procedure can be totally mechanized so that a machine can expose a slit hologram per each frame a footage at a very rapid pace. The advantage of this type of hologram is that you can now have a hologram of almost anything you can capture on ordinary film without the need of the expensive, clumsy pulse ruby laser. The disadvantage is that it is not truly a hologram but photographic information holographically stored. It seems that it will have a very solid place in the growing field of display and advertising holography. The image hologram which was mentioned earlier also has an advantage which will make it one of the types widely used in display holography. The image hologram can be played back with ordinary "white light" from an uncoated incandescent bulb. An image hologram can be either reflection type or transmission type however, it is more impressive as a transmission type because unlike an ordinary transmission hologram the image transmission hologram can play back well with an unfiltered white light source.

3.4 The Common Properties Of Hologram

The following characteristics of images are common for all holograms.

1. Holograms are true three-dimensional images. This is evidenced by the fact that you can move your head while viewing the image and see it in a different perspective. This includes revealing part of the image which was hidden at another viewing angle.
2. Every part of a hologram contains the image of the whole object. You can cut off the corner of a hologram and see the entire image through it, For every viewing angle you see the image in a different perspective, as you would a real object. Each piece of a hologram contains a particular perspective of the image, but it includes the entire object.
3. The holographic image scales with the wavelength. This initially caused great excitement because one could imagine making holographic images with x-rays and viewing them visible light, getting three-dimensional views of thing on the scale of molecule. X-ray holograms have yet to be made, and there are practical difficulties with the scaling, but there is still the possibility that this feature of holograms will prove to be of great benefit.

3.5 The Reconstructed Image

It is the image formed by illuminating the hologram (without any restriction on the illuminating method) i.e whether using the reference beam for illuminating the hologram or not.

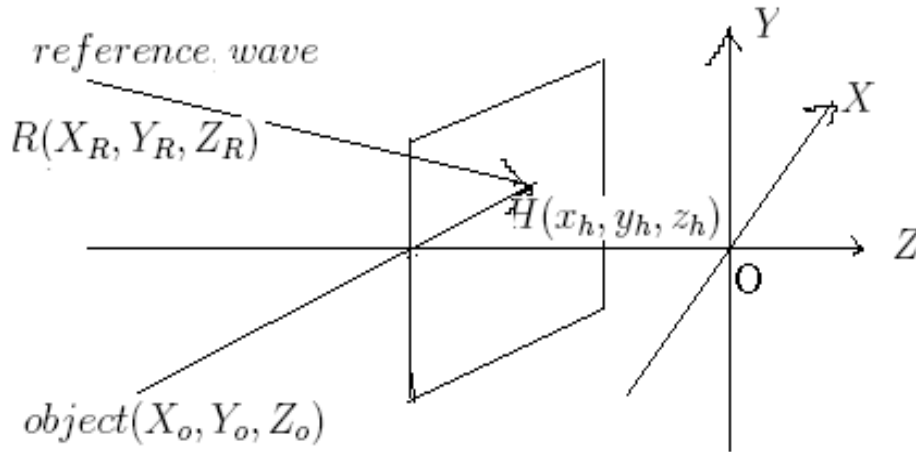


Figure 3.2: Hologram recording

To study the characteristics of the reconstructed image and their dependence on the optical system, we consider, as shown in Fig. 3.2. The hologram of a pointing object-recorded with a reference wave from a point source - using light wave length -. If the hologram is illuminated with monochromatic light of wave length- from a point source shown in figure 3.3. It can be shown that the coordinates of the image of are:

$$X_1 = \frac{X_o Z_o Z_p + \mu X_o Z_p Z - \mu X_p Z_p Z_o}{Z_o Z_R + \mu Z_p Z_R - \mu Z_p Z_o} \quad (3.5.1)$$

$$Y_1 = \frac{Y_o Z_o Z_p + \mu Y_o Z_p Z_R - \mu Y_R Z_p Z_o}{Z_o Z_R + \mu Z_p Z_R - \mu Z_p Z_o} \quad (3.5.2)$$

$$Z_1 = \frac{Z_p Z_o Z_R}{Z_o Z_R + \mu Z_p Z_R - \mu Z_p Z_o} \quad (3.5.3)$$

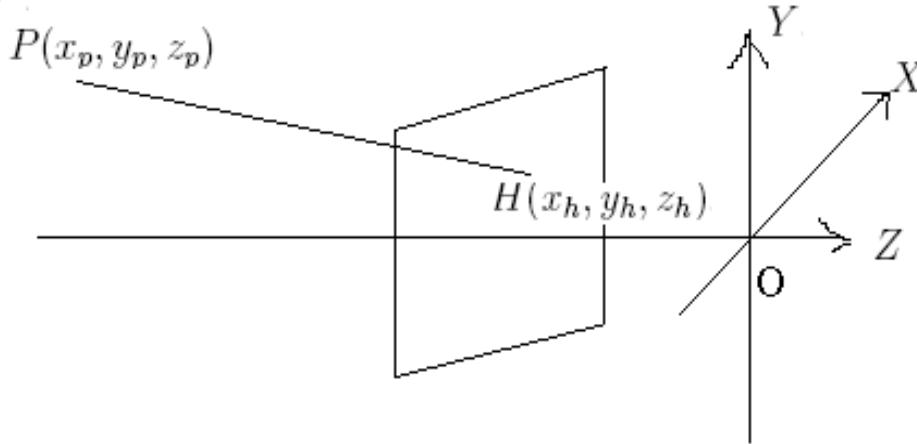


Figure 3.3: Image reconstruction

where $\mu = (\frac{\lambda_2}{\lambda_1})$ the lateral magnification of the image can be defined as

$$\begin{aligned} M_{lat} &= \frac{\Delta X_1}{\Delta X_o} \\ M_{lat} &= \frac{\Delta Y_1}{\Delta Y_o} \end{aligned} \quad (3.5.4)$$

$$M_{lat} = \frac{1}{1 + Z_o[\frac{1}{\mu Z_p} - \frac{1}{Z_R}]} \quad (3.5.5)$$

If the hologram is illuminated with the reference used to record it, the image has the same size as the original object and coincides with it. However, any change in the position or the wave length of the point source used for reconstruction results in a change in position and magnification of the reconstructed image.

Chapter 4

EXPERIMENTAL SETUP AND THE METHOD

4.1 Aim Of The Experiment

The aim of the experiment is:

- To make a split beam transmission hologram
- To determine the lateral magnification by using a He-Ne laser and the diode laser.

4.2 Materials Required (Apparatus)

- Helium Neon laser ,5mW and Diode laser,3mW
- Heavy metallic (holographic)table
- Beam splitter
- Film holder
- Power meter

- LED (light emitting diode) dark room light
- Object for hologram
- Instant holographic film
- Object direction mirror, Reference direction mirror
- Double concave lenses
- Ruler for measuring length
- Black card for aligning laser light
- Uncoated film plate for aligning laser light

4.3 Experimental Procedure (Method)

To Construct a hologram

1. A heavy holographic metallic plate positioned in a best position to make a hologram (this is in order to prevent any vibration or movement)
2. Place the laser ,object direction mirror ,beam splitter,reference direction mirror and the film holder in their approximation position .The film holder should have the thumb on the opposite side from the object area.The figure shows a general configuration for making the highest quality transmission holograms -lay out the component as shown in the figure 4.1
3. Equalize the beam path by using cord ,start from the beam splitter BS ,and measure the total distance from BS to M_2 and on H. Now measure the distance

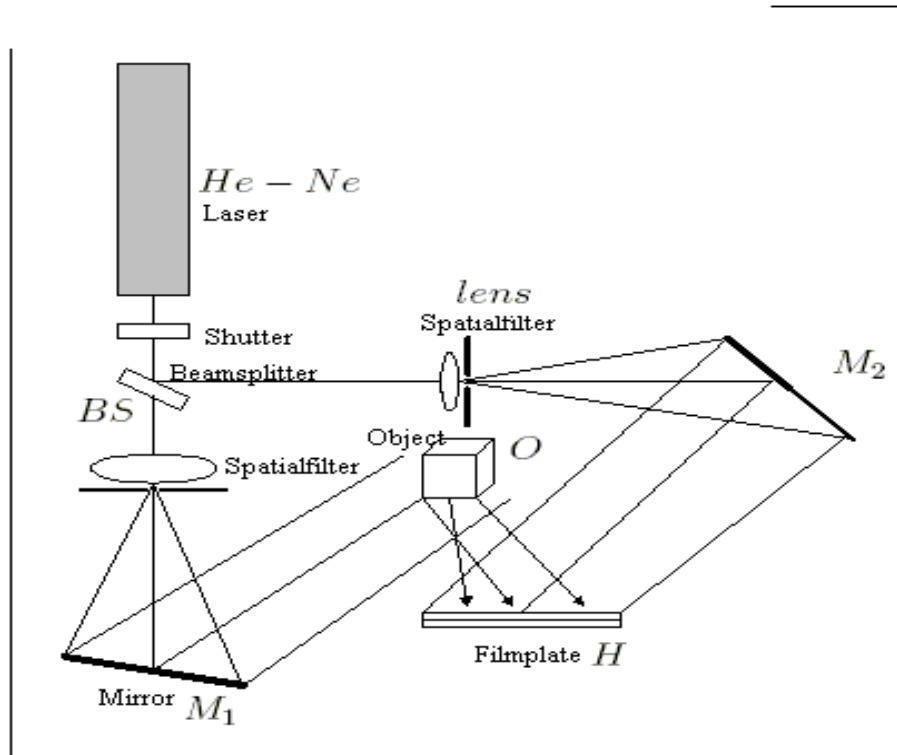


Figure 4.1: Recording transmission hologram

from BS to M_1 , on to the center of the object O and onto H . Equalize the paths within 2 or 3cm by moving mirror M_2

4. Expand the two beam by positioning lenses as shown the reference beam should cover the holoplate (here substituted by a white card during alignment) .The object beam should light up the object.
5. Baffling ,from the position of the holo plate ,carefully observe light scattered from any where other than from the object and the reference beam .Block all the unwanted light using black card board

6. Measure the intensity ratio of the two beam incident on the holo plate with power meter by positioning the meter at the location of the holo plate .Adjust the intensity ratio of reference beam to the object beam reading about 4:1 to 8:1 by two methods :

- Use a variable beam splitter
- Move the beam expanding lenses appropriately along the beam path



Figure 4.2: Experimental setup

7. In the dark with only the safe light ,insert the film into the film holder with the emulsion facing the object ,gently tighten the nylon screws and step back for a minute to let the table stop moving and allow their to settle .We can tell

which side the emulsion on by lightly wetting our lips and touching the film between them for a few seconds .As we part our lips one side will stick that is the emulsion side .Turn on the LED dark room light (green light) and turn off all other light (using the LED dark room light will allow to see quite well in the dark with out harming the film ,since the film is not red sensitive)

8. With all the lights turned off to open the litholo instant hologram film box and open the inner bag removing one film plate to leave the remaining film plate in the box and close the box
9. Now expose and determine the exposure time.

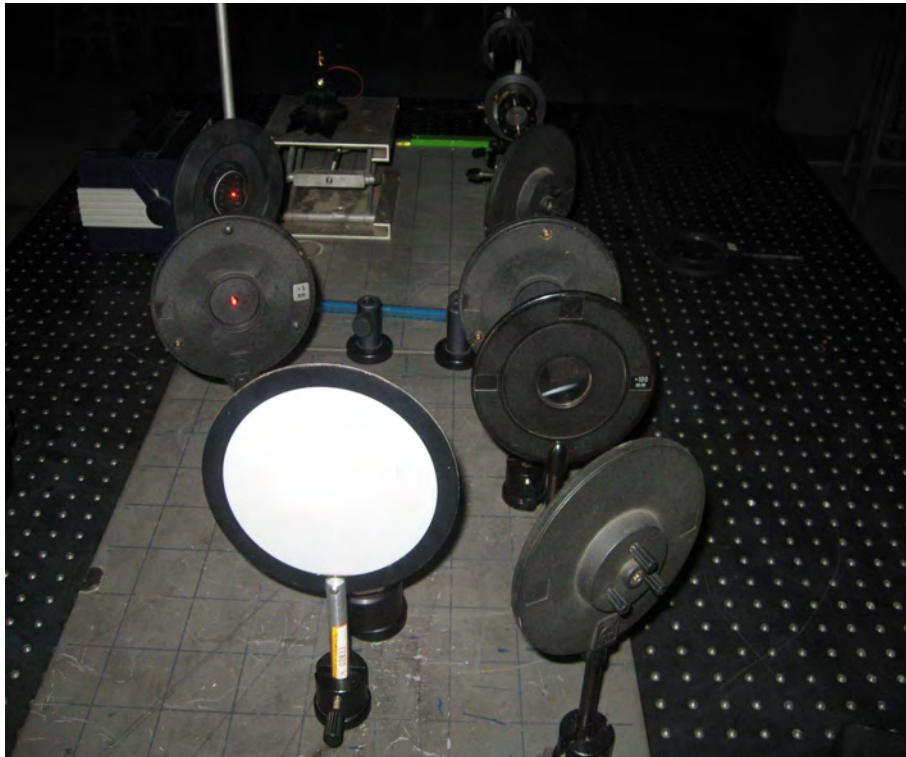


Figure 4.3: Reconstruct setup

10. To Reconstruct a hologram

11. Remove the object replace the beam splitter with the direction mirror (this will put the all the laser light into reference beam)
12. Adjust the components so that the reference beam through the lens illuminates the film .
13. Look through the film and see the image of the object in its original location on the table . (we may shave slightly rotate the film holder in relation to the reference beam because of emulsion shrinkage)
14. To determine the lateral magnification of the holographic image by changing the separation between illuminating laser source and the hologram (by measuring the height of the image at those location the data is reported in table 1 and 2)

Chapter 5

RESULTS and DISCUSSION

Constructing a hologram is too much difficult ,even if we have the latest and modern holographic kits, because the holographic and laser properties are sensitive to any movement of the object,the film ,or the optics caused by acoustic vibration or air movement. These will make the trains of waves change by more than a fraction of a wavelength ,the interference pattern will also move and the pattern is obliterated. when we come to our project work ,i used a diode laser for 15 to 18 minutes time of exposer but we could not got any fringes pattern formed on a holographic plate .After this we have changed laser source with helium -neon laser and we tried to construct for time of exposer 18 minutes and more.we found that a foggy like pattern after many trial and by taking for along time (1hr to 2hr).When we reconstructed nothing is seen or happen clearly but some dot like interference fringes are seen dispersedly .Then finally we decided to check wether the film works or expired by exposing it to light source so the result showed that the film is expired because it doesn't response automatically to the light given off ,Moreover ;when we see it the emulsion part of the holoplate,it is dried,shrink, and forms some scattered pattern . Because of this

failure we have changed instead of constructing a hologram ,we tried to reconstruct the one which is perfectly completed hologram from the optics laboratory .Then measurements are taken using this hologram and we found the following results. The figure shown below is the scanned of this transmission hologram.

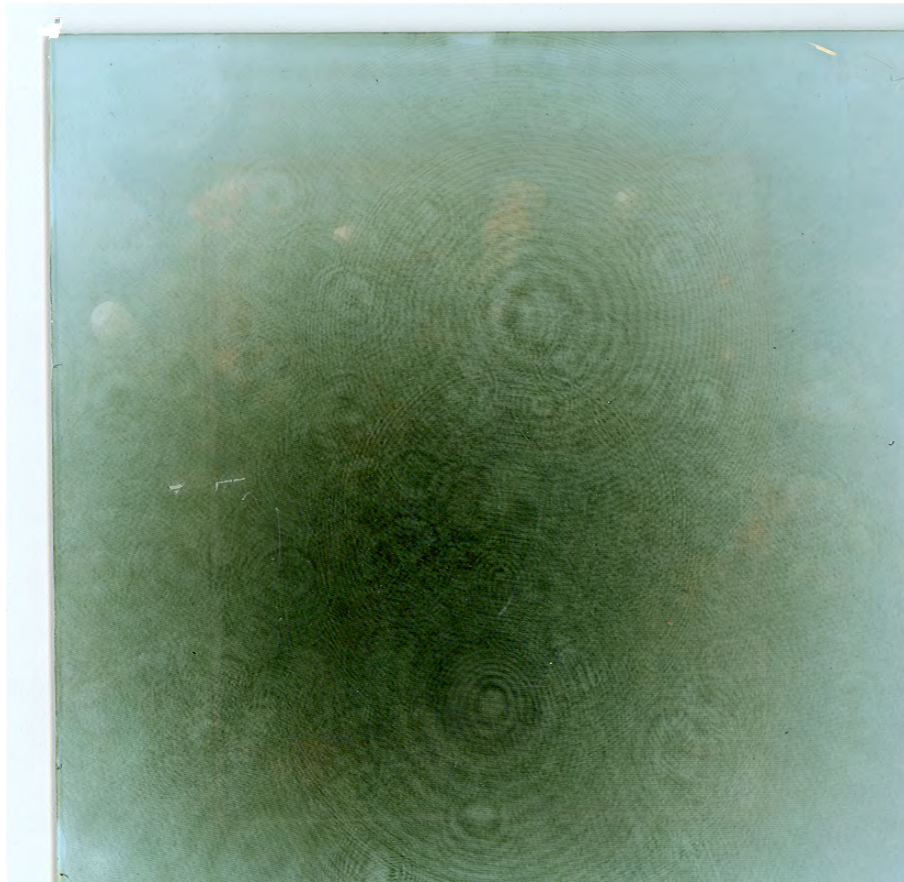


Figure 5.1: Scanned hologram front view

Table 1 To measure the height of the image(hologram) by using different Z_p (the horizontal separation between the illuminating beam and the hologram) here the hologram is illuminated with helium -neon laser,where the following terms represents

- dY_o -the object height
- dY_1 -the image height
- Z_p -distance of the point source
- Z_o -distance of the object =3.00cm
- Z_R -distance of the reference beam =40.00cm

$$\frac{\Delta M}{M_{lat}} = \frac{\Delta Z_o}{Z_o} + \frac{\Delta Z_p}{Z_p} + \frac{\Delta Z_R}{Z_R}$$

$$\mu = [(1 - M_{lat}) \frac{Z_p}{Z_o M_{lat}} + \frac{Z_p}{Z_R}]^{-1} \quad (5.0.1)$$

$Z_o(cm)$	$Z_p(cm)$	$dY_o(cm)$	$dY_1(cm)$	M_{lat}	$\frac{\Delta M}{M_{lat}}$
3.00	40,00	5.00	5.00	1.00	0.038
3.00	35.00	5.00	4.95	0.99	0.038
3.00	30.00	5.00	4.90	0.98	0.039
3.00	25.00	5.00	4.75	0.95	0.039
3.00	20.00	5.00	4.65	0.93	0.040
3.00	15.00	5.00	4.30	0.86	0.043
3.00	10.00	5.00	4.15	0.83	0.045
3.00	5.00	5.00	3.40	0.68	0.056

Table 5.1 The data measured and computed magnification using a He-Ne laser .

For each $Z_o, Z_p,$ and $M_{lat},$ using equation 5.0.1, i got the following results $\mu_1 = 1.00, \mu_2 = 1.01, \mu_3 = 1.04, \mu_4 = 0.94, \mu_5 = 0.99, \mu_6 = 0.94, \mu_7 = 1.07, \mu_8 = 1.09,$

$$\mu_{ave} = \frac{\mu_1 + \mu_2 + \mu_3 + \mu_4 + \mu_5 + \mu_6 + \mu_7 + \mu_8}{8}$$

Then the averaged value becomes $\mu_{ave} = 1.01$, The measurement is length and the least unit of the instrument is 0.1cm .Then we used 0.10cm for each of these ΔZ_o , ΔZ_P , ΔZ_R , from the table we can determine the error ΔM (used to determine μ) ≈ 0.038 , $\mu = 1,01 \pm 0.038$. since the hologram is illuminated by laser used for recording and reconstructing the holoplate therefore;

$$\mu = \frac{\lambda_1}{\lambda_2}$$

must be equal to one,when the result compared with the actual wavelength of the error can be given

$$errorpercentage = \left(\frac{1.01-1}{1}\right) * 100percent, =1 \text{ percent}$$

Table -2 To measure the height (dY_1) of the image of the hologram by using different Z_p ,here the hologram is illuminated by another diode laser whose wavelength is unknown.

$Z_o(cm)$	$Z_p(cm)$	$dY_o(cm)$	$dY_1(cm)$	M_{lat}	$\frac{\Delta M}{M_{lat}}$
3.00	40.00	5.00	5.05	1.01	0.038
3.00	30.00	5.00	5.00	1.00	0.039
3.00	20.00	5.00	4.80	0.96	0.041
3.00	10.00	5.00	4.20	0.84	0.045

Table 5.2 The data measured and computed magnification using a Diode laser .

$$\frac{\Delta M}{M_{lat}} = \frac{\Delta Z_o}{Z_o} + \frac{\Delta Z_p}{Z_p} + \frac{\Delta Z_R}{Z_R}$$

$$\mu = \left[(1 - M_{lat}) \frac{Z_p}{Z_o M_{lat}} + \frac{Z_p}{Z_R} \right]^{-1}$$

Also using equation 5.0.1 and for each Z_o, Z_p , and $M_{lat,i}$ got the following results

$$\mu_1 = 1.15, \mu_2 = 1.33, \mu_3 = 1.29, \mu_4 = 1.13$$

$$\mu_{ave} = \frac{\mu_1 + \mu_2 + \mu_3 + \mu_4}{4}$$

$$\mu_{ave} = 1.23,$$

From the table the error ΔM (used to determine μ) ≈ 0.039 where in terms of error

$$\mu = 1.23 \pm 0.039,$$

$\lambda_1 = 1.23 * 632.5nm = 759.0nm$ when this result compared with the actual wavelength of the diode laser (in our laboratory) the error in percentage will be

$$error\ of\ percentage = \frac{759.0 - 660}{660} * 100 = 14.8\ percent$$

Here we can determine if there is a laser of unknown wavelength by measuring and calculating the lateral magnification of the hologram. Note that, we encounter problems with measuring the size of the image (dy1), measuring length the clarity of the image affect the result what we have got and the intensities due to the optical mirrors also affects. The precision or uncertainty of measuring and more defect of the measuring device also another problem. But by minimize these errors, we could have an accurate measured (calculated) wavelength.

5.1 CONCLUSION

It is known that making a hologram needs more care and attention to get a good result. Hence one should have a totally darkroom and place be free from any vibration creating places. If one arrange the setup in such away that the ratio between the reference beam and object beam is according to the theoretical requirement and a

laser with some how greater power needed for constructing .Moreover; in identify the exact exposure time will be possible to make a better hologram therefore using this type of hologram we could measure the wavelength of the unknown laser and the the magnification with more accuracy . At last,i would like to inform that nowadays a holography has many different application such as storage media ,particle imaging ,holography interferometer (which is most important in natural science) holographic optical elements and it is a wide research area for scientist and engineers but in our country there is no such applications and studies widely . But there is no way to get even a single film for my project work .

- Making a hologram needs more care and attention to get a good result
- One should have a totally darkroom and place be free from any vibration creating
- Identify the exact exposure time will be possible to make a better hologram
- Measure the wavelength of the unknown laser and the the magnification with more accuracy .
- Arrange the setup in such away that the ratio between the reference beam and object beam is according to the theoretical requirement
- A laser with some how greater power needed for constructing
- Increase magnification by viewing hologram with longer wavelength

In order to do experiments based on holography in our laboratory and to have good knowledge for further application and studies a great effort is needed from the department , some other educational institutional ,and intellectuals involved in the area

! The following points are important in order to do the holography in our laboratory

- Importing each and every optical equipments of holography for researchers
- Prepare darkrooms for laboratory work for graduate as well as under graduate students
- Introduce holography using seminars,workshop ,and exhibition.
- Advisor have to encourage students to do their research in this area .

Chapter 6

APPLICATIONS OF HOLOGRAPHY

6.1 Data storage Holographic memory

Holography can be put to a variety of uses other than recording images. Holographic data storage is a technique that can store information at high density inside crystals or photo polymers. The ability to store large amounts of information in some kind of media is of great importance, as many electronic products incorporate storage devices. As current storage techniques such as Blu-ray reach the denser limit of possible data density (due to the diffraction-limited size of the writing beams), holographic storage has the potential to become the next generation of popular storage media. The advantage of this type of data storage is that the volume of the recording media is used instead of just the surface. Currently available SLMs (spatial light modulator) can produce about 1000 different images a second at 1024x1024-bit resolution. With the right type of media (probably polymers rather than something like LiNbO₃), this

would result in about 1 gigabit per second writing speed. Read speeds can surpass this and experts believe 1-tera bit per second readout is possible. In 2005, companies such as Optware and Maxell have produced a 120 mm disc that uses a holographic layer to store data to a potential 3.9 TB (terabyte), which they plan to market under the name Holographic Versatile Disc. Another company, In Phase Technologies, is developing a competing format. While many holographic data storage models have used "page-based" storage, where each recorded hologram holds a large amount of data, more recent research into using submicrometre-sized "microholograms" has resulted in several potential 3D optical data storage solutions. While this approach to data storage can not attain the high data rates of page-based storage, the tolerances, technological hurdles, and cost of producing a commercial product are significantly lower.

6.2 Security hologram

Security holograms are very difficult to forge because they are replicated from a master hologram which requires expensive, specialized and technologically advanced equipment. They are used widely in many currencies such as the Brazilian real 20 note, British pound 5/10/20 notes, Canadian dollar 5/10/20/50/100 notes, Euro 5/10/20/50/100/200/500 notes, South Korean won 5000/10000 notes, Japanese yen 5000/10000 notes, etc. They are also used in credit and bank cards as well as Books, DVDs, Sports Equipment.

6.3 Art

Early on artists saw the potential of holography as a medium and gained access to science laboratories to create their work. Holographic art is often the result of collaborations between scientists and artists, although some holographers would regard themselves as both an artist and scientist. Salvador Dal claimed to have been the first to employ holography artistically. He was certainly the first and most notorious surrealist to do so, but the 1972 New York exhibit of Dal holograms had been preceded by the holographic art exhibition which was held at the Cranbrook Academy of Art in Michigan in 1968 and by the one at the Finch College gallery in New York in 1970, which attracted national media attention. A small but active group of artist use holography as their main medium and many more artists integrate holographic elements into their work. The MIT Museum and Jonathan Ross both have extensive collections of holography and on-line catalogues of art holograms.

6.4 Holographic interferometry

holographic interferometry (HI) is a technique which enables static and dynamic displacements of objects with optically rough surface to be measured to optically interferometric precision (i.e. fractions of a wavelength of light). It can also be used to detect optical path length variations in transparent media which enables, for example, fluid flow to be visualized and analyzed. It can also be used to generate contours representing the form of the surface.

6.5 Interferometric microscopy

The hologram keeps the information on the amplitude and phase of the field. Several holograms may keep information about the same distribution of light, emitted to various directions. The numerical analysis of such holograms allows one to emulate large numerical aperture which, in turn, enables enhancement of the resolution of optical microscopy. The corresponding technique is called interferometric microscopy. Recent achievements of interferometric microscopy allow one to approach the quarter-wavelength limit of resolution.

6.6 Dynamic holography

In static holography, recording, developing and reconstructing occur sequentially and a permanent hologram is produced. There also exist holographic materials which do not need the developing process and can record a hologram in a very short time. This allows to use holography to perform some simple operations in an all-optical way. Examples of applications of such real-time holograms include phase-conjugate mirrors ("time-reversal" of light), optical cache memories, image processing (pattern recognition of time-varying images), and optical computing. The amount of processed information can be very high (terabit/s), since the operation is performed in parallel on a whole image. This compensates the fact that the recording time, which is in the order of a s, is still very long compared to the processing time of an electronic computer. The optical processing performed by a dynamic hologram is also much less flexible than electronic processing. On one side one has to perform the operation

always on the whole image, and on the other side the operation a hologram can perform is basically either a multiplication or a phase conjugation. But remember that in optics, addition and Fourier transform are already easily performed in linear materials, the second simply by a lens. This enables some applications like a device that compares images in an optical way. The search for novel nonlinear optical materials for dynamic holography is an active area of research. The most common materials are photorefractive crystals, but also in semiconductors or semiconductor heterostructures (such as quantum wells), atomic vapors and gases, plasmas and even liquids it was possible to generate holograms. A particularly promising application is optical phase conjugation. It allows the removal of the wavefront distortions a light beam receives when passing through an aberrating medium, by sending it back through the same aberrating medium with a conjugated phase. This is useful for example in free-space optical communications to compensate for atmospheric turbulence (the phenomenon that gives rise to the twinkling of starlight).

6.7 Determining Cubic Dimensions

Holographic scanners are in use in post offices, larger shipping firms, and automated conveyor systems to determine the three-dimensional size of a package. These statistics are used in billing and quality control, as well as enabling factory automation computer systems to pre-pack a given volume, such as a truck or pallet for bulk shipment. Joined with other scanners and a checkweigher, everything to be known on each package can be determined and transmitted via a network such as ethernet, to a data collection system. For instance, package weight, length, width, depth(cubic dimensions), and bar code information can be collected and analyzed in automation.

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