HOLOGRAPHIC APPLICATONS

By

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To my family

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Abstract

Holography is a technique of recording the whole information of an object by using a ***reference beam*** which is combined with the light from the object (an ***objec****t or scene* ***beam***). If these two beams are coherent, optical interference between the reference beam and the object beam, due to the superposition of the light waves, produces a series of intensity fringes that can be recorded on standard photographic film. The fringes form diffraction grating called hologram. When viewed from different angles or changing orientation it seems the object is still present and the image appears three dimensional. It is a lens less image recording technique. Hologram and holographic products are used in various products like currency, credit cards, etc. Also it is applied to combat counterfeit, for security purpose, for attractive product packaging and so on.

INTRODUCTION

The development of science helps human being to study further about nature from the invisible to the visible huge bodies. Studying light pushed him to concentrate on optics that improves his way of making images on two dimensional (2D) surfaces and further studies enables him to construct three dimensional (3D) image formations called **Hologram** by using LASER. That is why when we think of holography surveying laser is very important.

Holography becomes a popular art of science and helps the world in many ways.

The first chapter tries to recall the background knowledge about the nature of light and its properties like interference which is caused by two or more waves coming from different sources of waves. It also gives us basic information how to apply diffraction gratings.

The second chapter consists of definitions and explanations of principles of laser production, types and applications of laser.

The third chapter mainly focuses on holography, how it is formed, and processes it, types of hologram, characteristics and so on.

The last chapter, the main objective of the author, gives the general applications of holography in many fields of science, technologies, art, advertisement, and so on which holography is contributing to the world.

1 LIGHT

1 -1 LIGHT WAVES

Properties of light can be described in terms of wave motion. As in the case of water wave on surfaces of water bodies transverse wave motion is apparent. But light wave propagation presents greater observational difficulties. Since the oscillation frequencies of the electric and magnetic fields of a light wave approach 10^{15} Hz, there is no detector with response rapid enough to record their instantaneous values.

In 1802 Thomas Young demonstrated that light propagates as a wave and inferred(concluded) the wave properties from observation of interference of light coming from separated points on wave fronts. As shown in figure 1.1 he observed the overlap, on a screen, of the light from two secondary sources and found that there was cancellation of light intensity as well as addition which is difficult to account for on a particle basis but easily accommodated by a wave theory.

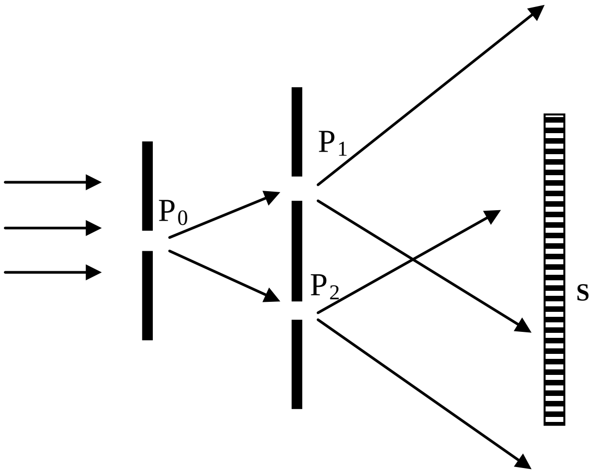


Figure. 1.1 Young's double slit experiment.

A hole P_0 is illuminated by collimated light, diffracts a spherical wave to an opaque screen some distance away containing two additional holes P_1 and P_2. These holes also diffract spherical wave fronts of secondary, phase related spherical waves. Finally on the screen S, parallel to the first slit and placed where the waves overlaps, an alternating bright and dark interference patterns are observed, with linear fringes running perpendicular to the direction of the line joining P_1 and P_2.

Observation of the wave properties of light and formation of hologram are closely related. Both depend on recording the intensity of black and dark spatial patterns or fringes found whenever coherent light waves intersect. The formation of the fringes pattern implies that light has a wave character, and measurement of the spacing and contrast of the fringe pattern can reveal the properties of the wave such as wavelength and degree of coherence.

According to Maxwell the presence of the two vector force fields, electric and magnetic, in light which propagates in space unsupported by any known medium, and only the time averaged effects of their(electric and magnetic) interaction with matter can be observed.

Holography is concerned with the interaction of light waves with photo sensitive matter, e.g., silver halide grains in photographic emulsion.

As Weiner (1890) demonstrated a light standing wave pattern blackened a photographic plate most at the electric field antinodal regions and not at all the magnetic field antinodal regions. Therefore the electric fields are the major consequence in the forming of holograms, and also for all the photosensitive media in which hologram have been formed.

1.2 INTERFERENCE

picture of interference

One of the most important wave properties is that interference. It is the effects of superposition of electromagnetic fields of two or more waves that overlap and arrive at the same place in space.

The superposition is stated as:

> ***the resultant disturbance of a point where overlapping occurs is the algebraic sum of the individual constituent wave at the location***.

The net disturbance depends on the two quantities, amplitude and phase. If the waves partially or completely cancel each other we call it ***destructive***, or if a region exists where the resultant trough and crest are more pronounced than the source waves we call it *constructive*. These phenomena are very important for construction of holograms.

The recording of a hologram is essentially a measurement of the intensity of an interference pattern. If the relative phase between the interfering wave fields has some degree of constancy in time then the spatial distributions of fringes of intensity in the interference pattern will also have some degree of constancy.

Let us focus our attention on the interference of monochromatic waves of identical wavelength produced from a single continuously oscillating source.

When light interacts with photosensitive emulsion (media) the darkening of a unit volume of photographic emulsion or the bleaching of a unit volume of photographic material is a function of the energy absorbed by that volume averaged over a time long compared to the light vibration period. This absorbed energy can be determined by Maxwell’s theory. According to his theory the energy u per unit volume or energy density in the electric field of the light wave is given by

$$u = \frac{1}{2}\varepsilon \boldsymbol{E} \cdot \boldsymbol{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{1.2.1}$$

Where ε is the dielectric constant and E the electric field vector.

The time average of u is

$$< u > = \frac{1}{2T}\int_{-T}^{T} u dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2.2$$

$$= \frac{1}{2T}\int_{-T}^{T} \frac{1}{2}\varepsilon \boldsymbol{E} \cdot \boldsymbol{E} dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2.3$$

$$= \frac{1}{2} \cdot \frac{1}{2T}\varepsilon \int_{-T}^{T} \boldsymbol{E} \cdot \boldsymbol{E} dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2.4$$

$$= \frac{1}{2}\varepsilon < \boldsymbol{E} \cdot \boldsymbol{E} > \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2.5$$

At any point in the light wave the pointing vector may be interpreted as: magnitude and direction of the energy flow per unit time per unit area normal to the flow. Which is classically called ***Intensity*** of the light at a point.

The intensity at a point P is given by

$$I_p = v < u > \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2.6$$

$$= \frac{1}{2}\varepsilon < \boldsymbol{E} \cdot \boldsymbol{E} > \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2.7$$

The discussion of monochromatic light waves will show that the intensity I_p reduces to the square of the amplitude of a light wave and is a very important parameter in holography.

If electric field exists as a physical quantity it must be a real function of space and time, and if it represents a truly monochromatic light wave it must be a simple harmonic function of time represented by

$$\boldsymbol{E} = E_O \cos(K \cdot r - \omega t + \varphi) \ldots\ldots\ldots\ldots 1.2.8$$

Or in complex form

$$\boldsymbol{E} = E_O \exp i(K \cdot r - \omega t + \varphi) \ldots\ldots\ldots\ldots 1.2.9$$

When we are dealing with light illuminating a given area it is measured by the amount of average light energy per unit area per unit time arriving at that area which is known as IRRADIANCE (or INTENSITY of light).

In holography it is usual to define intensity in the abbreviated form such that

$$I = 2 < \boldsymbol{E} \cdot \boldsymbol{E} > \ldots\ldots\ldots\ldots 1.2.10$$

$$= 2[1/2T \int_{-T}^{T} \boldsymbol{E} \cdot \boldsymbol{E} dt \ldots\ldots\ldots\ldots 1.2.11$$

$$= 1/T \int_{-T}^{T} E_O \cos(2\pi \nu t + \varphi) \cdot E_O \cos(2\pi \nu + \varphi) \ldots\ldots\ldots\ldots 1.2.12$$

$$= 1/T \int_{-T}^{T} E_O \cdot E_O cos^2(2\pi \nu t + \varphi)\, dt \ldots\ldots\ldots\ldots 1.2.13$$

But, $cos^2(2\pi \nu t + \varphi) = \frac{1}{2}\,(1 + \cos 2(2\pi \nu t + \varphi) \ldots\ldots\ldots\ldots 1.2.14$

$$= \frac{1}{2}\,(1 + \cos(4\pi \nu t + 2\varphi) \ldots\ldots\ldots\ldots 1.2.15$$

Hence, $I = \frac{1}{2T} \int_{-T}^{T} E_O \cdot E_O [\{1 + cos(4\pi \nu t + \varphi)\}]\, dt \ldots\ldots\ldots\ldots 1.2.16$

$$= \frac{1}{2T} E_O \cdot E_O \int_{-T}^{T} [\{1 + cos(4\pi \nu t + \varphi)\}]\, dt \ldots\ldots\ldots\ldots 1.2.17$$

$$= \frac{1}{2T} E_O \cdot E_O [2T + 0] \ldots\ldots\ldots\ldots 1.2.18$$

$$\therefore I = E_O \cdot E_O \ldots\ldots\ldots for\ T \gg 1/f \ldots\ldots\ldots\ldots 1.2.19$$

Therefore, $I = E_0^2 \ldots\ldots\ldots\ldots 1.2.20$

$$= E_{0x}^2 + E_{oy}^2 + E_{0z}^2 \ldots\ldots\ldots\ldots 1.2.21$$

Thus intensity is equal to the square of amplitude of the electric field which provides no information about the phase of the wave. According to supper position principle, the interference of different light waves at a point yields a resultant electric field E due to the separate fields $\boldsymbol{E_1}$, $\boldsymbol{E}_2$, ….

Where $\boldsymbol{E} = \boldsymbol{E}_1 + \boldsymbol{E}_2 + \cdots$ ……………………………………………..……….1.2.22

The resultant of the interference of two monochromatic wave sources S_1 and S_2 at positions r_1 from S_1 and r_2 from S_2 on a reference point P becomes

$$E(r,t) = E_{01} expi(k \cdot r_1 - wt + \varphi_1) + E_{02} expi(k \cdot r_2 - wt + \varphi_{21}) \quad \text{……...1.2.23}$$

According to equation 1.2.22

$$\Rightarrow E \cdot E = (E_1 + E_2) \cdot (E_1 + E_2) \quad \text{……………………………….…………1.2.24}$$

$$= E_1 \cdot E_1 + E_1 \cdot E_2 + E_2 \cdot E_1 + E_2 \cdot E_2 \quad \text{………………….…………1.2.25}$$

$$= E_1 \cdot E_1 + E_2 \cdot E_2 + 2E_2 \cdot E_1 \text{………………………………………1.2.26}$$

$$= I_1 + I_2 + I' \text{…………………………………..…….…………1.2.27}$$

Where I_1 is the irradiance from S_1

I_2 is the irradiance from S_2 and

I' is the irradiance from combinations of S_1 and S_2

Using trigonometric relation one can find for the value

$$2 < E_1 \cdot E_2 > = 2E_{01}E_{02} [\cos k \cdot (r_1 - r_2) + (\varphi_1 - \varphi_2)] \quad \text{…………..……1.2.28}$$

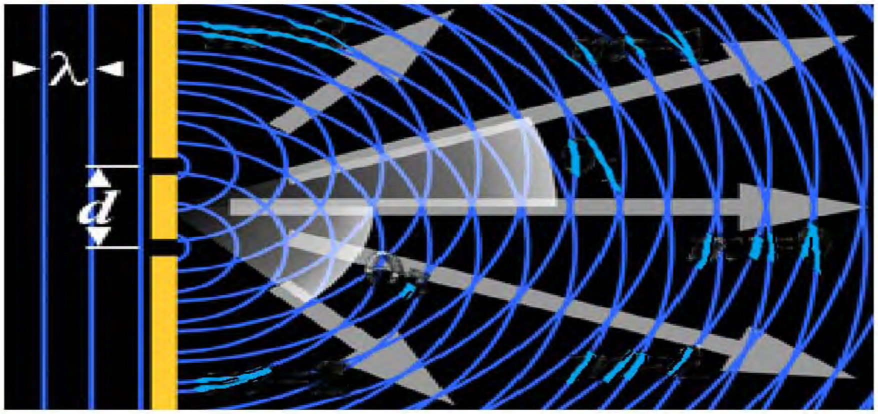
$$E \cdot E = I_1 + I_2 + I' \text{………………… …………………………1.2.29}$$

Then Equation 1.2.28 $=< E_1 \cdot E_1 > + < E_2 \cdot E_2 > +2 < E_1 \cdot E_2 >$…………………1.2.30

$$= I_1 + I_2 + 2E_{01}E_{02} [\cos k \cdot (r_1 - r_2) + (\varphi_1 - \varphi_2)] \quad \text{…..………1.2.31}$$

Here the irradiance of the two point sources mainly depends on the third term especially on the phase difference term k$(r_1 - r_2) + (\varphi_1 - \varphi_2)$. The difference in phase between the interference waves coming from $S_1$and S_2 must constant for certain duration to form maximum (bright) and minimum (dark) irradiance which are known as INTERFERENCE FRINGES. These patterns are very useful in the formation of holograms.

1-3 Diffraction



Picture of diffraction

It is the bending of wave normal rays when they encounter obstacles whose optical transmission or reflection properties change significantly in distances approaching the wavelength of the illuminating light.

A hologram itself is a diffracting object with some peculiar properties. Holograms can be classified as behaving like

1- plane diffraction grating
2- volume diffraction grating

The grating may consists of a set of periodically spaced transparent slits in an opaque object (or screen).

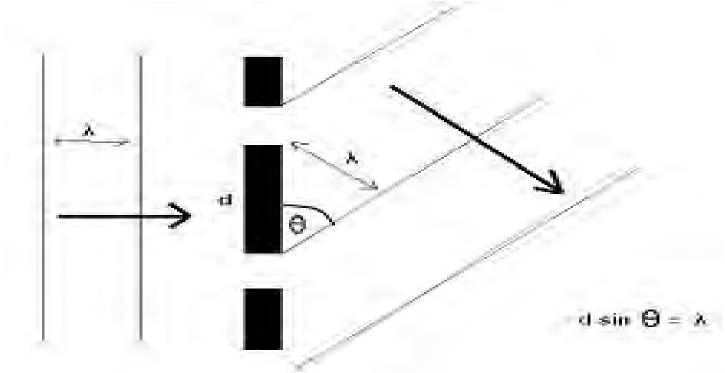


Figure1.2 Plane diffraction due to two slits

Diffraction effect occurs when part of the wave front is removed by an aperture or stop. The importance of diffraction effects depends on the scale of the obstacle or aperture compared with the wave length.

1- **plane diffraction grating**

when a plane wave is incident on a grating as shown in figure 1.2 the condition determining the in-phase or constructive addition of diffracted light is the grating equation,

$$d(sini\ +\ sin\delta) =\ \lambda \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.3.1$$

where d is grating spacing, i is angle of incidence and δ is the angle of diffraction

2- **Volume diffraction**

A volume diffraction grating consists of periodically space scattering planes illuminating with a plane wave, which is shown in figure 1.3.

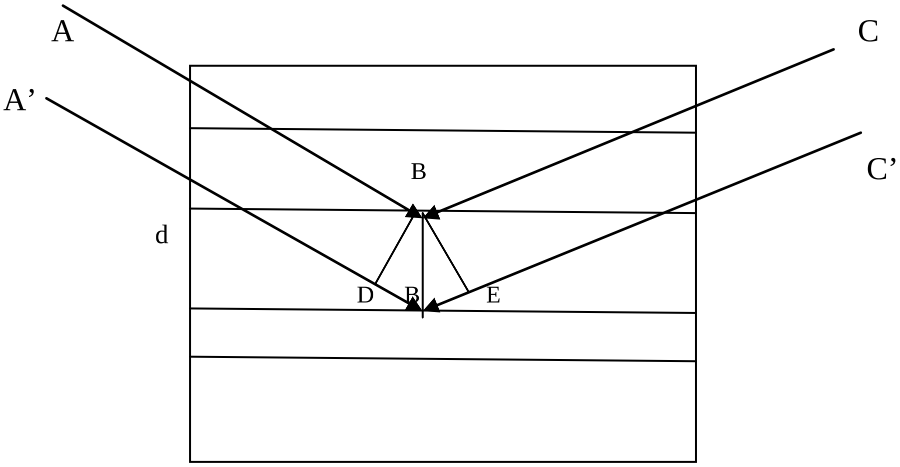


Figure 1.3. Volume diffraction grating

The same principle in phase addition of light scattered by successive planes to obtain maximum output, is applied here with the result that

$$2dsin\theta = \lambda\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.3.2$$

According to Bragg’s law,

$$DB' +\ B'E = dsin\theta + dsin\theta\ \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.3.3$$

$$= 2dsin\theta\ =\ \lambda\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.3.4$$

It is this equation that determines constructive interference and diffraction of a plane wave. Maximum diffraction occurs when the angle of incidence θ and reflection are equal as shown in the figure.

For maximum diffraction observation, volume diffraction equation is selected. The first Bragg’s equation has limitations of $/sini/$ and $/sin\delta/\leq 1$

2 LASERS

2-1 Introduction

In the early 1950s a device known as the **MASER** (an acronym for ***Microwave Amplification by Stimulated Emission of Radiation***) that produce and amplifies microwave came in to being through the efforts of Charles Hard Townes(USA), Alexander Michailovich Prokhorov(USSR) and Nikolai Gennadievich Basov(USSR). All of whom shared the 1964 Nobel Prize in physics. It is an extremely low noise used for low noise microwave frequency amplifier. Having high stability of the generated frequencies, it serves in time standards in atomic clocks.

1958 Townes and Arthur L. Schawlow set forth the general physical condition that would have to be met in order to achieve light amplification by stimulated emission of radiation.

And then in July 1960 Theodore H. Maiman announced the first successful operation of an **Optical MASER** or **LASER**, which is the great milestone in the history of science.

The first laser was built in 1960 and within a decade laser beams spanned the range from infrared to ultra violet. The availability of high power coherent sources led to the discovery of a number of new optical effects.

Laser is a device that produces and amplifies light. The light produced by laser is very pure in color, can extremely intense, and can be directed with great accuracy. That is why it is highly directional. Lasers can generate light from infrared through the x-ray range.

In atoms lasers generates light by storing energy by the electrons while being excited or move to the excited state. Thus electrons are almost the source of all lights. Light is composed of tiny packets of energy called ***Photons.***

Laser produces coherent light which is monochromatic.

Electrons travel in orbits and exist only in certain specific energy states or level. When the electrons move from the lower energy level to the higher absorbs energy. The photon absorbing atom whose energy is the difference between the two energy levels. Then the atom becomes excited. The electrons which are excited quickly jumps or return back to the lower energy level by giving off the extra energy as ***light*** or ***Radiation***.

Today lasers are in use everywhere: in reading video disks, cutting steels in factories, scanning labels in supermarkets, performing surgeries in hospitals, etc.

2-2 Radiation

Except black body all physical bodies radiates heat to their surrounding as they received from the outside. In the case of black bodies we can consider it as a small box having a very small hall in it when light or heat reaches its surface entering the hole will have less chance to come out but stays inside due to internally reflections. Since there is no radiation by the body it seems black. The name black body is given this way.

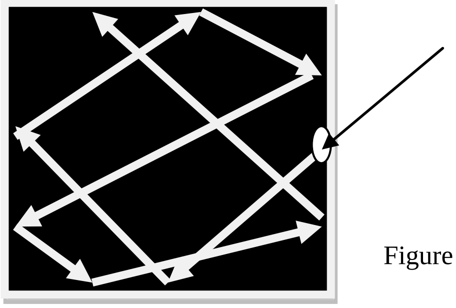


Figure 2.1 black body

Once a wave enters the hole its probability to come out is too small. The number of modes (which are possible standing waves in the cavity) per unit volume within the frequency interval dν is given by

$$n(\nu)d\nu = 8\pi\frac{v^3}{c^3}dv \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2.1$$

The average energy per unit volume for the total number of modes within the cavity

when thermal equilibrium is reached is given by the Rayleigh – Jeans law.

$$\rho(v)dv = 8\pi\frac{v^2}{c^3}k_BTdv \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . .\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2.2$$

Where k_BT represents the classical oscillator’s mean energy and k_B is Boltzmann constant, T absolute temperature.

The equation matches with experimental results in the infrared region but not with experiments at higher frequencies. Plank reconciles this by his famous hypothesis that energy is radiated in discrete form or quantized.

$$E = nhv \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

Where n is positive integer in which energy exchange requires discrete amount of energy hν for which the above equation is the energy of a mode containing n photons. Therefore the average energy of the mode is

$$< E > = \frac{hv}{exp\left(\frac{hv}{k_BT}\right) - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

And hence equation 2. 2 becomes

$$\rho(v)dv = \frac{8\pi v^2}{C^3 \exp\left(\frac{hv}{k_B T}\right) - 1} hvdv \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

Thus equation 2.5 is the famous Plank's radiation law that matches with experiments.

2-3 Absorption

If molecules with energy level E_1 & E_2 are brought in to thermal radiation field they absorb photon of energy

$$hv = E_2 - E_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

This means that if the atom is not isolated other effects may occur. Photons of the same energy as the energy of the upper level may use their energy to move an electron from the lower to the upper level. This means that the molecule becomes excited to the higher level. The process of being excited by changing energy level from lower to higher is known as ***ABSORPTION***.

The probability per second that a molecule will absorb a photon ($d\Phi/dt$), is proportional to the number of photons of energy hν per unit volume and can be expressed in terms of the spectral energy density $\rho(v)$ of the radiation field as

$$W_{12} = \frac{d}{dt} \Phi_{12} = B_{12}\rho(v) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.7$$

The constant B_{12} is Einstein coefficient of absorption.

2-4 Emission

Consider a container filled with a certain gas in equilibrium at a relatively low room temperature. At this temperature most of the atoms will be in the ground state while some of the atoms having enough energy will be in the excited state.

According to Maxwell-Boltzmann distribution the number of atoms in any excited state N_i per unit volume is

$$N_i = N_0 \exp\left(-\frac{\varepsilon i}{k_B T}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.8$$

Where N_o is constant at a given temperature.

Since our interest is in the atomic transition between arbitrary states like the j-state where $\varepsilon_j > \varepsilon_i$, then at the j-state

$$N_j = N_0 \exp\left(-\frac{\varepsilon j}{k_B T}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

The ratio of the population occupying the two states will be

$$\frac{Ni}{Nj} = \frac{N0 \exp\left(-\frac{\varepsilon i}{k_B T}\right)}{N0 \exp\left(-\frac{\varepsilon j}{k_B T}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.10$$

But from equation 2.6 we have

$$\varepsilon_j - \varepsilon_i = h v_{ji} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.11$$

Therefore we get

$$N_j = N_0 \exp\left(-\frac{hvji}{k_B T}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.12$$

A photon having adequate amount of energy interacts with an atom in its lowest energy or ground state imparting that energy to the atom thereby causing the electron cloud to take on a new configuration. The atoms jump into a high – energy exciting state.

Such an excess-energy configuration is mostly exceedingly short lived (10nanosecond or so). Without any external influence the atom will emit its overload of energy as a photon and back to its stable state in the process called SPONTANEOUS EMISSION.

2-4.1 Spontaneous Emission

It is dependent on the electron being in the upper level. Let us consider an idealized atom with two energy levels and one electron as shown in figure 2.2.

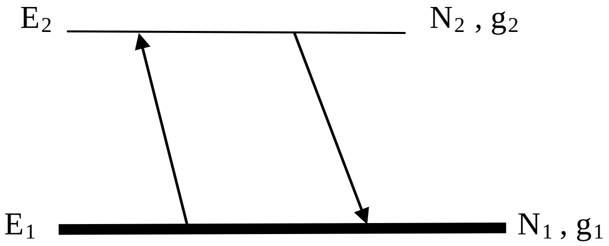


Figure 2.2 the two energy level model

The electron may be in either of the two energy levels. If the electron is in the higher level it may fall down to the lower level. If it does it must give up a certain amount of energy equal to the energy difference between the two levels. This is the law of conservation of energy being applied. This energy is given up in the form of light.

Light is also quantized. It may be represented as a group of photons. Each photon carries one quantum of light energy. The amount of this energy in the quantum depends on the wavelength (color) of light

$$E = h\frac{c}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

Where E is the energy of the photon λ is the wavelength, h & c are fundamental constants.

Thus from equation 2.13 we can see that a short wavelength wave such as blue at 470nm has a high energy, and red light at 670nm has low energy per photon. Here the important point is that the wavelength of light is linked to the energy of a photon in a defined way. Thus our electron in the idealized atom, which has given out a photon of defined energy, emits light of a certain defined wavelength or ***color***.

Thus without external influence the atom emits light spontaneously in the process called ***SPONTANEOUS EMISSION***. In this process the photon may travel in any direction and can be emitted at any time.

The probability per second that a photon spontaneously is emitted by a molecule depends on the molecule and the selected transition but is independent of the external radiation field.

$$w_{21} = \frac{d}{dt}\Phi = A_{21} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2.14$$

Where A_{21} is Einstein's coefficient of spontaneous emission and is often called the spontaneous transition probability.

2-4.2 Stimulated Emission

The radiation field can also induce molecules in the excited state E_2 to make transition to the lower state E_1 with simultaneous emission of photon energy hv. This process is known as STIMULATED OR INDUCED EMISSION. The induced photon energy is emitted to the same mode which caused the emission. This means that the number of photons in the mode is increased by one. The probability d/dt that one molecule emits one induced photon per second is

$$w_{21} = \frac{d}{dt}\Phi_{21} = A_{21} = \mathrm{B}_{21} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots..2.15$$

So for the stimulated emission to be greater than the spontaneous emission we need many photons in the laser. For the stimulated emission to be greater than stimulated emission N_2 should be greater than N_1 which means more atoms have their electrons in the upper level than in the lower level. This is known as INVERSION. This may be seen from the fact that in the absence of external influence, i.e., no photons(n=0) the only process which can occur is spontaneous emission which allows any electron that began in the upper level to fall to the lower level but not vice versa.

At thermal equilibrium the ground level is far more populated than the excited level as shown in the figure 2.3(a) below. While an inversion population is a situation where the exited level is the most populated as shown in figure2.3(b)

a) Thermal equilibrium

b) population inversion

Figure 2.3 Energy level of an atom at different situations.

By an external action on the collection of atoms it is possible to obtain an out of equilibrium situation where the ratio between the populations is different from the equilibrium. It is more populated than the ground level, the collection of atoms is then said to contain inversion of population. The problem in producing a laser is creating inversion in the populations of the two levels

2-5 Amplification

Assuming now we have an inversion, $N_2 > N_1$ and considering a single photon entering a region with the atoms in. the photon will pass by an atom with its electron in the upper level and cause it to emit a second photon traveling in the same direction, by the process of stimulated emission in two more atoms to give four photons and so on.

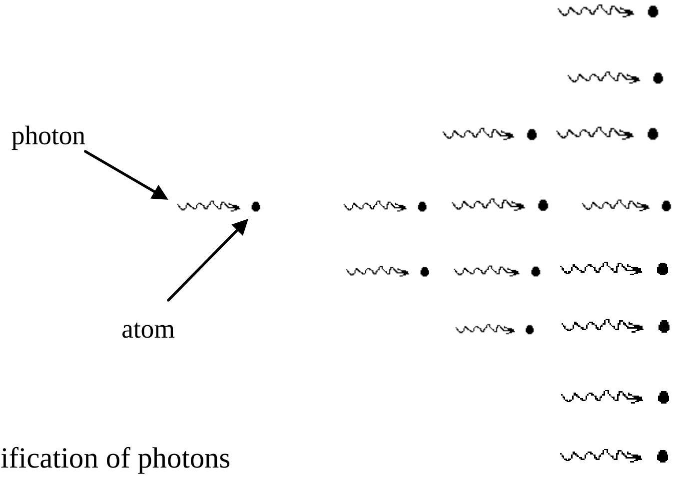


Figure 2.4. Amplification of photons

Thus we have amplification which is also known as GAIN. The region containing the atoms is known as the GAIN MEDIUM. The final stage in a laser is to get the first photon to amplify. This is done by placing the gain medium between two mirrors that forms the so called a laser CAVITY shown in figure 2.5.

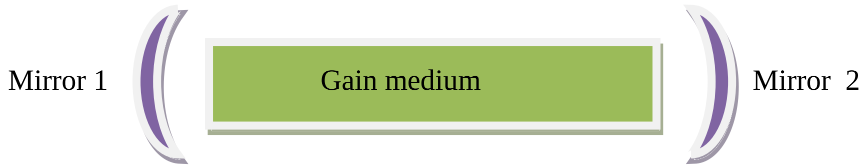


Figure 2.5 laser cavity. Gain medium with reflection mirrors

Initially there is no light in the cavity. The only possible process for the atoms to undergo is therefore spontaneous emission, and this duly occurs. As stated earlier this may travel in any direction out of the gain medium and most will lost from the cavity. However out of the millions of photons emitted by the millions of atoms in any real medium there is bound to be at least one which travels directly to one of the mirrors and is reflected back to the gain medium. This is now our first photon. As it passes through the gain medium it causes stimulated emission as described earlier and by the end of the gain medium there are, say 10 photons. Now the important part is that these are all travel in the same direction as the first photon, so it will be reflected back to the gain region by the other mirror. This 10 photons now each cause stimulated emission, and when they get out of the medium to the first mirror again there are one hundred which are reflected back to the gain medium again and are amplified to 1000 etc…

Thus we very rapidly get very many photons traveling back and forth in the cavity. In an idealized atom case where no photons are lost from the steady amplified beam, the photon number just goes on increasing. But in any real laser some photons are lost, for many different reasons. One of this is quite deliberate. One of the mirrors is made to reflect only part of the light, and to allow the rest through. This is then the output beam of the laser and the leaky mirror is referred to as the output coupler. A steady state may then be reached where the gain exactly replaces the photons lost from the cavity by the output coupler. There is then a constant number of photons in the cavity any time.

The output beam thus has photons which are traveling in a fixed direction and also have fixed wavelength (or color) defined by the energy levels of the electrons in the atoms of the gain medium. Laser produces special images in holography which includes Transmission hologram, rainbow hologram and reflection holograms.

2-6 Construction of laser

As shown in figure 2.6 a laser has two parallel mirrors, of which one of them is nearly perfect reflector and the other partially, facing each other to form resonator to allow light reflecting back and forth along the optical axis. Active medium which amplifies the stimulated light is placed between the mirrors. The active medium is pumped using pumping mechanism so that it can be excited from its lower energy level. Photons can move in any direction but those photons travelling along the optical axis will oscillate. The other photons will either be absorbed or scattered. Finally most of the photons will oscillate along the optical axis. Thus for every stimulated emission the photons number increases. Hence under proper conditions the light density is amplified. Eventually the partially reflecting mirror will transmit laser light either in continuous wave (cw) or in pulsed way.

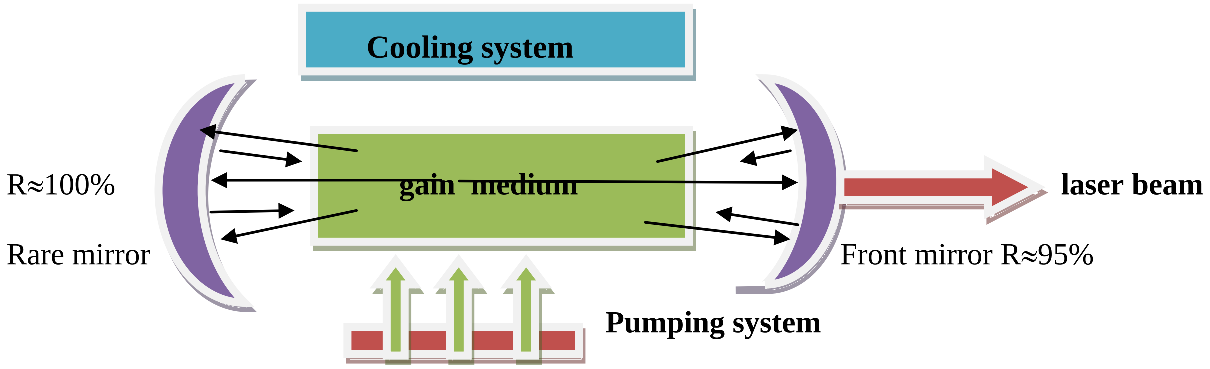


Figure 2.6 Basic laser system

The basic three parts of laser source are

a) The active medium
b) The pumping energy mechanism
c) Optical resonator

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

2-7 Properties of laser beam

Coherency:- Laser light differs from all other light sources, man-made or natural, in one basic way which leads to several characteristics. Laser light can be **coherent** light. Ideally, this means that *the light being emitted by the laser is of the same wavelength, and is in phase*. 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. Other properties of laser beam are monochromatic, highly directionality, brightness and less divergence makes it special.

2-8 Types of lasers

Lasers are generally classified according to the material, called the gain medium use to produce the laser light. Solid-state, gas, liquid, semiconductor, and free electron are all common types of lasers.

A. Solid state laser

Solid-state lasers produce light by means of a solid medium. The most common solid laser media are rods of ruby crystals and neodymium-doped glasses and crystals. The ends of the rods are fashioned into two parallel surfaces coated with a highly reflecting nonmetallic film. Solid-state lasers offer the highest power output. They are usually pulsed to generate a very brief burst of light. Bursts as short as 12×10^{-15} sec have been achieved. These short bursts are useful for studying physical phenomena of very brief duration.

One method of exciting the atoms in lasers is to illuminate the solid laser material with higher-energy light than the laser produces. This procedure, called pumping, is achieved with brilliant strobe light from xenon flash tubes, arc lamps, or metal-vapor lamps.

B. Gas lasers

The lasing medium of a gas laser can be a pure gas, a mixture of gases, or even metal vapor. The medium is usually contained in a cylindrical glass or quartz tube. Two mirrors are located outside the ends of the tube to form the laser cavity. Gas lasers can be pumped by ultraviolet light, electron beams, and electric current or chemical reactions. The helium-neon laser is known for its color purity and minimal beam spread. Carbon dioxide lasers are very efficient at turning the energy used to excite their atoms into laser light. Consequently, they are the most powerful continuous wave (cw) that is, lasers that emit light continuously rather than in pulses.

C. Liquid lasers

The most common liquid laser media are inorganic dyes contained in glass vessels. They are pumped by intense flash lamps in a pulse mode or by a separate gas laser in the continuous wave mode. Some dye lasers are tunable, meaning that the color of the laser light they emit can be adjusted with the help of a prism located inside the laser cavity.

D. Semiconductor lasers

Semiconductor lasers are the most compact lasers. Gallium arsenide is the most common semiconductor used. A typical semiconductor laser consists of a junction between two flat layers of gallium arsenide. One layer is treated with an impurity whose atoms provide an extra electron, and the other with an impurity whose atoms are one electron short. Semiconductor lasers are pumped by the direct application of electric current across the junction. They can be operated in the continuous wave mode with better than 50 percent efficiency. Only a small percentage of the energy used to excite most other lasers is converted into light.

Scientists have developed extremely tiny semiconductor lasers, called quantum-dot vertical-cavity surface-emitting lasers. These lasers are so tiny that more than a million of them can fit on a chip the size of a fingernail.

Common uses for semiconductor lasers include compact disc (CD) players and laser printers. Semiconductor lasers also form the heart of fiber-optics communication systems (*see* Fiber Optics).

E. Free electron lasers

Free electron lasers employ an array of magnets to excite free electrons (electrons not bound to atoms). First developed in 1977, they are now becoming important research instruments. Free electron lasers are tunable over a broader range of energies than dye lasers. The devices become more difficult to operate at higher energies but generally work successfully from infrared through ultraviolet wavelengths. Theoretically, electron lasers can function even in the X-ray range.

2-9 Lasers Applications

The characteristics of laser light makes lasers a valuable tool in many areas, such as communication, industry, medicine, military and scientific research. And also a laser is applied in holography, which is our main concern. Some of the areas are:

> **Communication**: - laser working in the infrared area are right now revolutionizing the communication industry. A laser transmits voice or data via fiber optic cables at much improved speed and capacity. These lasers are part of the broadband revolution we hear about daily.

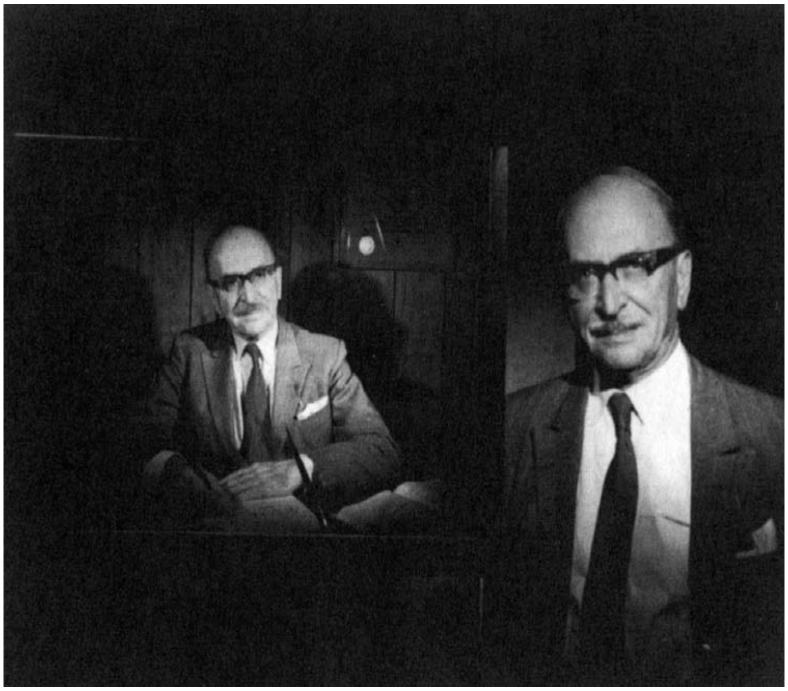
Industry: - lasers are used to cut, drill, weld, guide and measure with high accuracy.

Medicine: - surgeons use lasers to remove deceased body tissues, with little damage to surrounding area. In addition laser seal off blood vessels served during the surgery. Thus reduce the amount of bleeding.

Laser eye surgery is becoming common for correcting near sightedness as well as for reattaching retinas.

Military: - lasers are used in military applications both as weapons and for guidance systems for weapons. Future application may include very powerful lasers that can down planes and missiles.

3 HOLOGRAPHY



DANIS GABOR The father of this topic

3-1 Basics of Holography

"What is a hologram? And how does holography work?" Note that: the process is referred to as holography while the plate or film itself is referred to as a hologram. The terms holograms and holography were coined by the father of holography Dennis Gabor in 1947. The word hologram is derived from the Greek words "**holos**" meaning ***whole*** or complete and "**gram**" meaning ***message***. Older English dictionaries define a hologram as a document (such as a last will and testament) handwritten by the person whose signature is attached.

The theory of holography was developed by Dennis Gabor, a Hungarian physicist, in the year 1947. His theory was originally intended to increase the resolving power of electron microscopes. Gabor proved his theory not with an electron beam, but with a light beam. The result was the first hologram ever made. At that time there was no source of coherent radiation with sufficient intensity.

What was the light source he needed? The LASER was first made to operate in 1960.

Now that we know a little something about light in general, we may consider the light source needed to perform holography: the laser. 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 & Upatnieks (at the University of Michigan) reproduced Gabor's 1947 experiments with the laser, and launched modern holography. By 1964 they proved that holography was practical and that the use of laser light was an important factor. They were able to generate the 3D images by illuminating a photographic plate with light from a laser. Their work excited others to focus on holography.

The light emitted from a laser is all exactly the same type, or make, depending upon the characteristics of the substance which is lasing. I will explain in the next chapter what the term laser means, and how the laser works to give coherent light. Right now it is important to remember that the frequency of laser light is unvarying and that in the same medium, all light, i.e., light of different wavelengths of frequency, travels at the same speed.

It's true that all electromagnetic radiation, including the very small portion we call visible light, travels in a vacuum at the approximate finite speed of 186,000 miles per second. (Note, the velocity of light in a vacuum is one of nature's constants and is referred to by the letter c). Light waves, can oscillate at different frequencies and with correspondingly different wavelengths so that for any given amount of time, say one second, a greater number of shorter wavelengths of (blue) light would be emitted from a laser than longer wavelengths of (red) light. This does not mean that different wavelengths travel at different speeds.

Why we need laser for holography?

In order to maximize the visibility of fringes formed by the object and reference beams, while recording a hologram it is essential to use coherent illumination. In addition to being spatially coherent, the coherent length of the light must be much greater than the maximum value of the optical path difference between the object and the reference beams in the recording system. Lasers are therefore employed almost universally as light sources for recording holograms. We can use different lasers for holography. Here some of laser characteristics are listed in the table.

Laser	output	Wavelength(nm)	power
Ar^+	cw	514,488	1w
He – Cd	cw	442	25mw
He –Ne	cw	633	2-50mw
Kr^+	cw	647	500mw
Diode	cw	670-650	5mw
Diode-YAG	cw	532	100mw
Dye	cw	Tunable	200mw
Ruby	pulsed	694	1-10J

Table 2.1 lasers used for Holography.

But for a simple holographic system the (He-Ne) laser is the usual choice. It is inexpensive and operates on a single spectral line at 633nm which is well matched to the peak sensitivity of many photographic emulsions. In addition it does not require water cooling and has a long life.

3-2 THE BASIC HOLOGRAM

The hologram, that is, the medium which contains all the information, is nothing more than a high contrast, very fine grain, black and white photographic film. Silver halide emulsion much like the black and white film you can buy in your neighborhood drug store. The film designed especially for holography is capable of very high resolution. One way of judging resolution of film or lenses is to see how many distinguishable lines can be resolved within a certain width, in this case it's a millimeter. a good film designed for holography is able to resolve up to 3000 lines/mm. Holographic film is also especially prepared to be sensitive to a certain wave length of light Why the need for such special resolving power? The answer is that the hologram is not a recording of a focused image as in photography, but the recording of the interference of laser light waves that are bouncing off the object with another coherent laser beam, i.e., a reference beam which will be described later. The wavelengths of light from a He-Ne laser are approximately 24 micro-inches or twenty four millionths of an inch long, thus the need for such fine grain or high resolving power.

A hologram is an image recorded on a photosensitive plate or flat sensitive film. In a hologram a three dimensional (3D) image is recorded which is different from the ordinary or conventional photography.

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. There is a point to point correspondence between the object and the emulsion.

- In the ordinary photography imaging technique the intensity distribution in the original scene is recorded. Therefore all the information about the optical paths to different parts of the scene is lost.

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. 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.

- In holography technique case
  a) both the phase and the amplitude waves coming from the object are recorded.
  b) it uses coherent light illumination and using reference beam to convert the phase information into variation of intensity

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.

As soon as object beam 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.

3-3 CLASSIFICATION OF HOLOGRAMS

Holograms may be classified in a number of different ways depending on their thickness, method of recording, method of reconstruction etc.

Amplitude and Phase Holograms

A hologram may be of an absorption type which produces a change in the amplitude of the reconstruction beam. The phase type hologram

produces phase changes in the reconstruction beam due to a variation in the refractive index or thickness of the Roughness, Film medium. Phase holograms have the advantage over amplitude holograms of no energy dissipation within the hologram medium and higher diffraction efficiency. Holograms recorded in photographic emulsions change both the amplitude and the phase of the illuminating wave. The shape of the recorded fringe planes depend on the relative phase of the interfering beams. Consequently the reconstructed wave is reflected from the hologram according to the density of the silver deposited with the amplitude variation proportional to the amplitude of the object. Similarly the phase of the reconstruction wave is modulated in proportional to the products and services phase of the object wave. Thus both amplitude and phase of the object wave are reproduced.

Classification based on Hologram Thickness

Thin Holograms or Plane Holograms

Holograms may be thin (plane) or thick (volume). A hologram may also be regarded as thin if its emulsion thickness is much less than the fringe spacing.

As the angle difference between the object beam (or the wave fronts 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.
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 less than 90 degrees it's plane, from 90 degrees - 180 degrees it's volume.

A volume (thick) hologram may be regarded as a superposition of three dimensional gratings recorded in the depth of the emulsion each satisfying the Bragg law. The grating planes in a volume hologram produce maximum change in refractive index and/or absorption index. A consequence of Bragg condition is that the volume hologram reconstructs the virtual image at the original position of the object if the reconstruction beam exactly coincides with the reference beam. However, the conjugate image and higher order diffractions are absent.

The spatial distribution of fringes recorded by the photo emulsion throughout its entire emulsion forms volume hologram.

In-line and Off-axis holograms

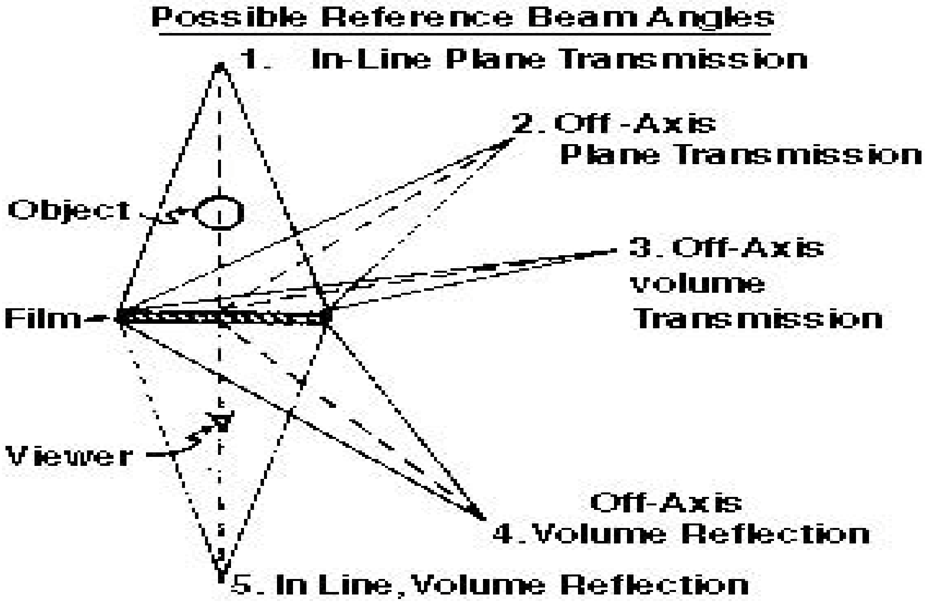


Figure 3.1making In-line and Off-axis hologram

The in-line hologram

We consider the optical system shown in fig. 1.5 in which the object (a transparency containing small opaque details on a clear background) is illuminated by a collimated beam of monochromatic light along an axis normal to the photographic plate.

The light incident on the photographic plate then contains two components. The first one is the directly transmitted wave, which is a plane wave whose amplitude and phase do not vary across the photographic plate. Its complex amplitude can, therefore, be written as a real constant *r*.

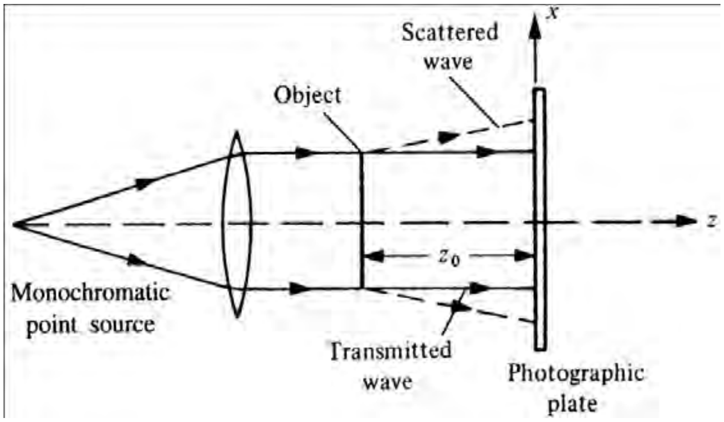


Fig. 3.2. Optical system used to record an in-line hologram.

Finally, the hologram is illuminated, as shown in fig. 3.2, with the same collimated beam of monochromatic light used to make the original recording.

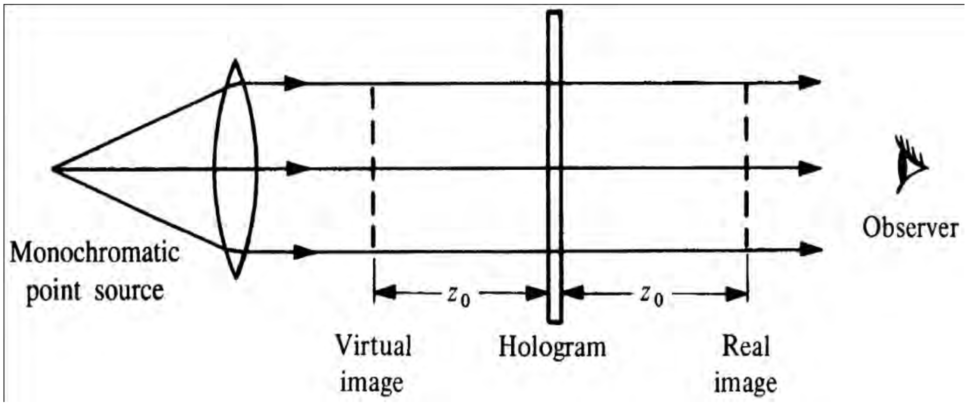


Fig. 3.3 Optical system used to reconstruct the image with an in-line hologram, showing the formation of the twin images.

With an in-line hologram, an observer viewing one image sees it superimposed on the out-of-focus twin image as well as a strong coherent background. Finally, the hologram must be a ‘positive’ transparency.

Off-axis holograms

The term off-axis means that the reference beam and object beam are not coming from the same direction.

To understand the formation of an image by an off - axis hologram, we consider the recording arrangement shown in fig. 3.4, in which (for simplicity) the reference beam is a collimated beam of uniform intensity, derived from the same source as that used to illuminate the object.

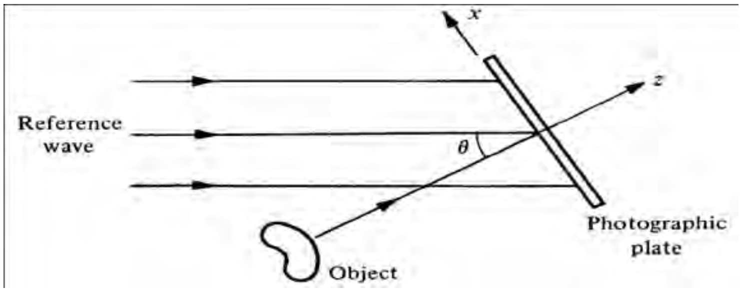


Fig. 3.4. The off-axis hologram: recording.

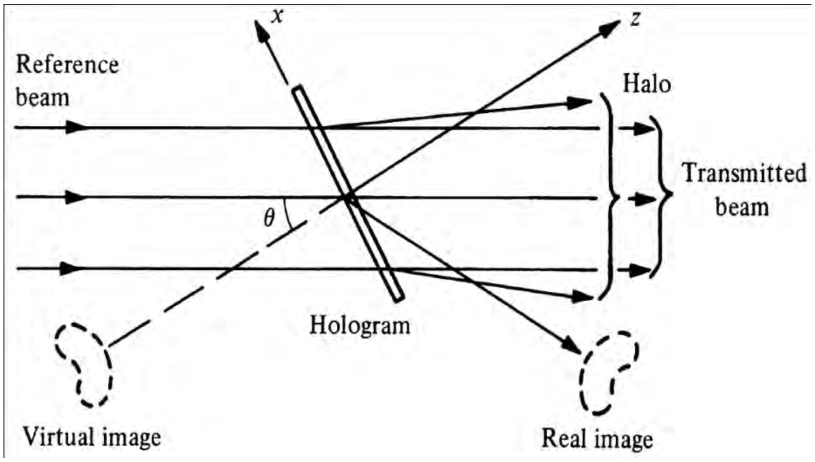


Figure 3.5 reconstruction of off-axis hologram.

If the offset angle of the reference beam is made large enough, the virtual image can be separated from the directly transmitted beam and the conjugate image.

In this arrangement, corresponding points on the real and virtual images are located at equal distances from the hologram, but on opposite sides of it. Since the depth of the real image is inverted, it is called a **pseudoscopic** image, as opposed to the normal, or **orthoscopic**, virtual image.

3-4 **Main Types of Holograms**

A hologram is a recording in a two- or three-dimensional medium of the interference pattern formed when a point source of light (the reference beam) of fixed wavelength encounters light of the same fixed wavelength arriving from an object (the object beam). When the hologram is illuminated by the reference beam alone, the diffraction pattern recreates the wave fronts of light from the original object. Thus, the viewer sees an image indistinguishable from the original object.

There are many types of holograms, and there are varying ways of classifying them. The basic types are listed as follows.

THE REFLECTION HOLOGRAM

The reflection hologram, in which a truly three-dimensional image is seen near its surface, is the most common type shown in galleries. The hologram is illuminated by a "spot" of white incandescent light, held at a specific angle and distance and located on the viewer's side of the hologram. Thus, the image consists of light reflected by the hologram. Recently, these holograms have been made and displayed in color their images optically indistinguishable from the original objects. If a mirror is the object, the holographic image of the mirror reflects white light; if a diamond is the object, the holographic image of the diamond is seen to "sparkle."

Although mass-produced holograms such as the eagle on the VISA card are viewed with reflected light, they are actually transmission holograms "mirrorized" with a layer of aluminum on the back.

3. THE TRANSMISSION HOLOGRAM

The typical transmission hologram is viewed with laser light, usually of the same type used to make the recording. This light is directed from behind the hologram and the image is transmitted to the observer's side. The virtual image can be very sharp and deep. For example, through a small hologram, a full-size room with people in it can be seen as if the hologram were a window. If this hologram is broken into small pieces (to be less wasteful, the hologram can be covered by a piece of paper with a hole in it), one can still see the entire scene through each piece. Depending on the location of the piece (hole), a different perspective is observed. Furthermore, if an undiverged laser beam is directed backward (relative to the direction of the reference beam) through the hologram, a real image can be projected onto a screen located at the original position of the object.

3. HYBRID HOLOGRAMS

Between the reflection and transmission types of holograms, many variations can be made.

Embossed holograms: To mass produce cheap holograms for security application such as the eagle on VISA cards, a two-dimensional interference pattern is pressed onto thin plastic foils. The original hologram is usually recorded on a photosensitive material called photoresist. When developed, the hologram consists of grooves on the surface. A layer of nickel is deposited on this hologram and then peeled off, resulting in a metallic “shim.” More secondary shims can be produced from the first one. The shim is placed on a roller. Under high temperature and pressure, the shim presses (embosses) the hologram onto a roll of composite material similar to Mylar. Embossed holograms are used in the security industry because they are difficult to counterfeit.

Integral holograms: A transmission or reflection hologram can be made from a series of photographs (usually transparencies) of an object—which can be a live person, an outdoor scene, a computer graphic, or an X-ray picture. Usually, the object is “scanned” by a camera, thus recording many discrete views. Each view is shown on an LCD screen illuminated with laser light and is used as the object beam to record a hologram on a narrow vertical strip of holographic plate (holoplate). The next view is similarly recorded on an adjacent strip, until all the views are recorded. When viewing the finished composite hologram, the left and right eyes see images from different narrow holograms; thus, a stereoscopic image is observed.

Multichannel holograms: With changes in the angle of the viewing light on the same hologram, completely different scenes can be observed. This concept has enormous potential for massive computer memories.

Computer-generated holograms: The mathematics of holography is now well understood. Therefore, we can dream up any pattern we want to see. After we decide what wavelength we will use for observation, the hologram can be designed by a computer. This computer-generated holography (CGH) has become a sub-branch that is growing rapidly. For example, CGH is used to make holographic optical elements (HOE) for scanning, splitting, focusing, and, in general, controlling laser light in many optical devices such as a common CD player.

120° Integral Stereogram (Multiplex)
A type of white light transmission hologram which is formed by recording multiple photographs onto a single hologram. The resulting image usually only provides horizontal parallax, and often provides the effect of an animated three dimensional image. 120° integral stereograms are not complete cylinders

360° Integral Stereogram (Multiplex)
A type of white light transmission hologram which is formed by recording multiple photographs onto a single hologram. the resulting image usually only provides horizontal parallax, and often provides the effect of an animated three dimensional image. 360° integral stereograms are complete cylinders, and are often mounted on a motor-driven base which allows them to rotate at a constant speed.

Computer Generated Stereogram
Hologram produced from multiple 2-d perspective recordings of computer-generated images. Images can be analog, animated, reduced or enlarged. This is an alternative to the analog hologram process, in which the subject is imaged directly onto the film with a laser exposure.

Dichromated Gelatin (reflection)
Dichromated Gelatin (DCG) is a chemical-gelatin mix that produces very bright images in a golden-yellow color. The images have the least range of depth, but they are viewable in normal room light without special spotlights.

Holographic Stereogram
Hologram produced from movie footage of a rotating subject. Images can be computer generated, animated, reduced or enlarged, or photographed on site. This is an alternative to the original hologram process, in which the subject is imaged directly onto the film with a laser exposure.

Rainbow Holograms

Reflection Holograms
Reflection Holograms are lit from the front, reflecting the light to you as you view it, like a painting or photograph hung on a wall. Different film emulsions produce images with different characteristics. (Silver Halide, Dichromated Gelatin, Photo Polymer)

White Light Transmission Holograms
White light transmission holograms are illuminated with incandescent light (white light) and produce images that contain the rainbow spectrum of colors. The colors change as the viewer moves up and down and are often called "rainbow" holograms.. Transmission holograms are lit from the rear (like a photographic transparency) and bend light as it passes through the hologram to your eyes to form the image.

Primary Support Options Film
Most holographic film is just like photographic film in many ways. It often contains photosensitive silver halide crystals. The major difference in holographic film is that it is capable of very high resolution. Holographic film is also specially designed to be sensitive to a particular wavelength of light.

Film (photopolymer)
Photopolymer is the newest of the recording materials. They have a plastic backing and are suitable for long production runs. The image depth of photo polymers is slightly less than that of silver halide; however, the images are brighter, with a wider angle of view.

Foil
Foil is often the support material for embossed holograms.

Glass
Sometimes emulsion is applied to glass, which provides greater stability than film during the exposure process.

Hard Plastic
Sometimes used as a support material for embossed holograms (such as record albums). Holographers occasionally apply emulsion to thick plastic just as they would to glass. Film can be made sturdier after being developed if it is laminated onto plastic sheets. This technique is most often used in large-format holography, since heavy glass plates would be difficult to safely manage.

Metal
Anything that is solid enough to retain an imprint image can be used to record a hologram. Metal is often used as a master shim(wedge shape), from which other holograms are embossed onto plastic or other material.

3-5 CHARACTERISTICS OF A HOLOGRAM

Holograms have certain unique characteristics. These are given below:
Hologram Aberrations: One of the basic characteristics of holograms is that they suffer from aberrations which are caused by a change in the wavelength from construction to reconstruction. This is also caused by a difference in the reference and reconstruction beams. There are two types of aberrations-chromatic and non-chromatic-which are important even when there is a small difference between the reference and reconstruction geometry. One simple way to eliminate all the aberrations simultaneously is to copy exactly one construction beam in the reconstruction process.

Orthoscopic and Pseudoscopic Images: A hologram produces two images, one which is real and the other a virtual image which is an exact replica of the object. However, to the appearance of the observer, the two images differ in appearance. The virtual image has the same appearance of depth and the parallax and produced at the same position as the original object. It appears that the observer is viewing the original object through a window defined by the size of the hologram. This virtual image is known as orthoscopic image. The real image is also formed in front of the hologram at the same time and at the same distance from the hologram. This real image is called pseudoscopic image where the scene depth is inverted.

Some Other Characteristics

It is possible to reconstruct the hologram of a diffuse object by a small portion of the hologram. In other words, if a hologram breaks into pieces, the entire image can be produced by each piece. However, as the size of the hologram reduces, a loss of image perspective, brightness and resolution result in the constructed image.

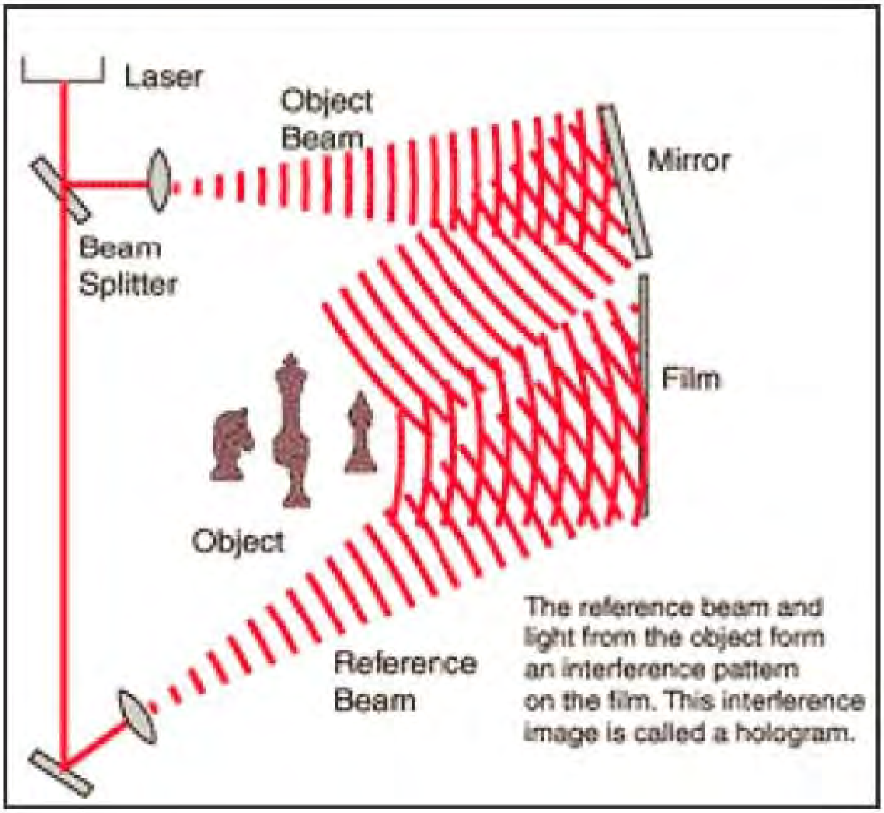
Another characteristic of hologram is that a contact print of a hologram will reconstruct a positive image which is not distinguishable from the image produced by the original.

A cylindrical hologram makes a 360 degree view of the object.

Without any cross-talk, more than one independent scenes can be stored in the same photographic plate and these can be viewed one at a time.

3- MAKING HOLOGRAMS

Holographic recording process



The reference beam and light from the object form an interference pattern on the film. This interference image is called a hologram.

Figure 3.6 Arrangement for holographic recording.

To produce a recording of the phase of the light wave at each point in an image, holography uses a ***reference beam*** which is combined with the light from the scene or object (the ***object beam***). If these two beams are coherent, optical interference between the reference beam and the object beam, due to the superposition of the light waves, produces a series of intensity fringes that can be recorded on standard photographic film. These fringes form a type of diffraction grating on the film, which is called the hologram..

General properties of recording materials for holography.

Material	**Reusable**	**Processing**	**Type of hologram**	**Max. efficiency**	**Required exposure [mJ/cm²]**	**Resolution limit [mm^{-1}]**
Photographic emulsions	No	Wet	Amplitude	6%	0.001–0.1	1,000–10,000
			Phase (bleached)	60%		
Dichromated gelatin	No	Wet	Phase	100%	10	10,000
Photoresists	No	Wet	Phase	33%	10	3,000
Photothermoplastics	Yes	Charge and heat	Phase	33%	0.01	500–1,200
Photopolymers	No	Post exposure	Phase	100%	1–1,000	2,000–5,000
Photochromics	Yes	None	Amplitude	2%	10–100	>5,000
Photorefractives	Yes	None	Phase	100%	0.1–50,000	2,000–10,000

Table 3.1 properties of recording materials.

This is possible because during holographic recording, each point on the hologram's surface is affected by light waves reflected from all points in the scene, rather than from just one point. It's as if, during recording, each point on the hologram's surface were an eye that could record everything it sees in any direction. After the hologram has been recorded, looking at a point in that hologram is like looking "through" one of those eyes.
In table 3.1 the principal materials for holographic recording are shown. The required exposure is for a long exposure. Short exposure times (less than 1/1000th of second, such as with a pulsed laser) require a higher exposure.

To demonstrate this concept, you could cut out and look at a small section of a recorded hologram; from the same distance you see less than before, but you can still see the entire scene by shifting your viewpoint laterally or by going very near to the hologram, the same way you could look outside in any direction from a small window in your house. What you lose is the ability to see the objects from many directions, as you are forced to stay behind the small window.

The first holograms were recorded already prior to the invention of the laser, and used other (much less convenient) coherent light sources such as mercury-arc lamps.

In simple holograms the *coherence length* of the beam determines the maximum depth the image can have. A good holography laser will typically have a coherence length of several meters, ample for a deep hologram.

Experimental Set up

One should follow the following steps before, while and after recording a hologram.

Precautions

- Chemicals should be treated with respect
- No need of talking
- Do not move (be still)
- Do not touch the table while exposure
- Turn off your mobile and other vibrating systems
- Use rubber gloves while developing
- Dispose the used developers and bleach properly

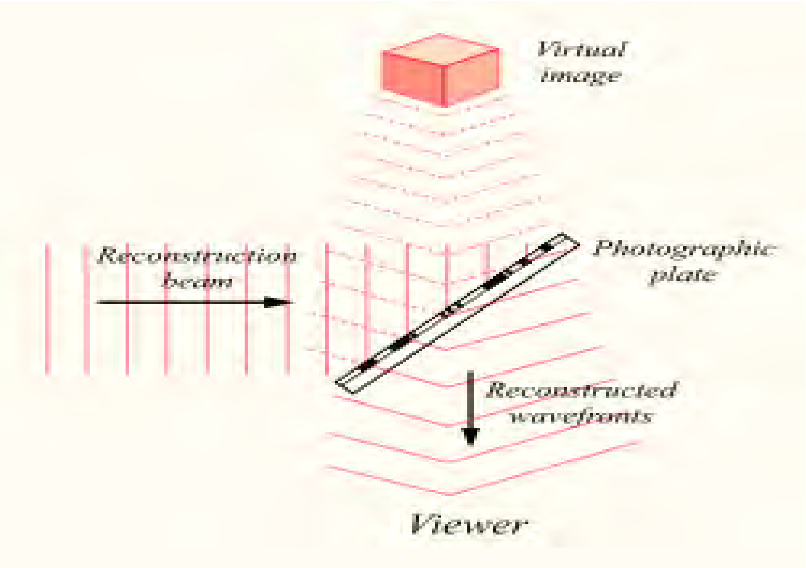
Steps to follow

- Choose a sturdy table or counter in a dark room that is free of noise, vibration, air currents, and small movements (creaky floors etc)
- Keep the table feet in sand filled cans to avoid vibrations
- Arrange the object, He-Ne laser, diverging lenses to spread the beams, mirrors according to the figure
- Position the laser till the subject is fully illuminated
- Make ready the developing chemicals
- Turn off dark room light; block any direct light from reaching the holography system.
- Open the box, take one film (plate) and immediately close the box.
- Place the plate on the plate holder
- Wait 10 – 20sec for the plate to settle
- Illuminate the hologram by removing the shutter that blocks the laser light from the source
- Block again the light
- Remove the plate from its holder
- Immediately start the developing process

Process of developing

- Mix the dried powder photo chemicals with distilled water to form two solutions, the developer and bleach.
- Dip and wiggle plate in developer for 20sec.
- Rinse the plate in water for 30sec.
- Dip and wiggle the plate in bleach for 20sec.
- Rinse in water for 30sec

3-7 RECONSTRUCTION OF HOLOGRAM

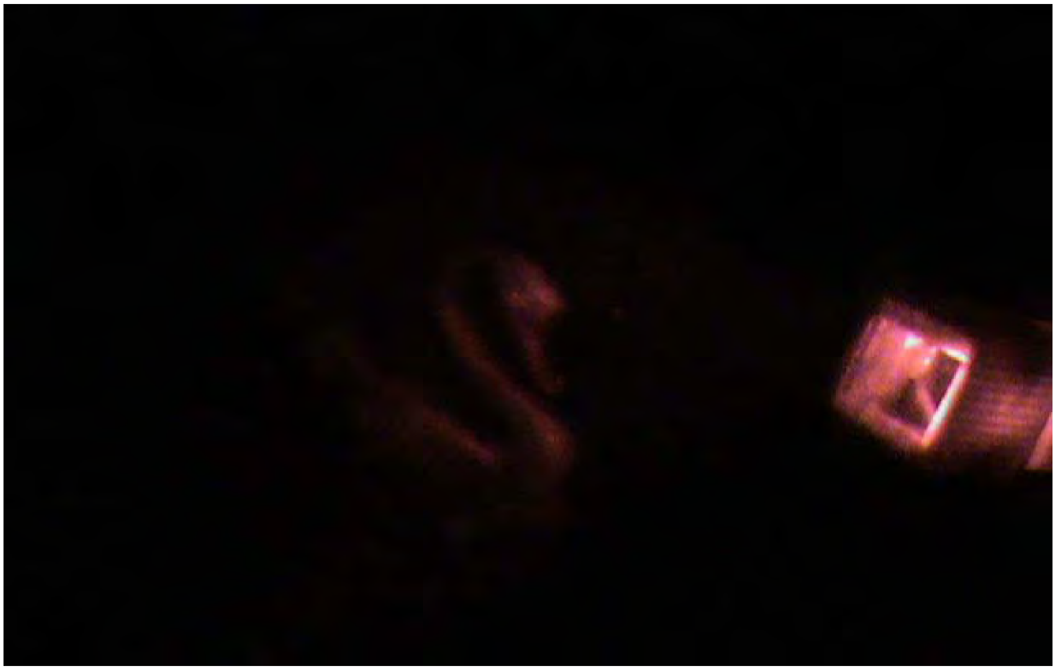


When the processed holographic film is illuminated once again with the reference beam, diffraction from the fringe pattern on the film reconstructs the original object beam in both intensity and phase.

Because many viewpoints are stored, each of the viewer's eyes sees the image from a slightly different angle, so the image appears three-dimensional. This is known as stereopsis. The viewer can move his or her viewpoint and see the image rotate exactly as the original object would.

The central miracle of holography is that when the recorded grating is later illuminated by a substitute reference beam, the original object beam is reconstructed, producing a 3D image

a) interference patterns



b) reconstruction of picture a)

Pictures made on a transmission hologram

Mass replication

An existing hologram can be replicated, either in an optical way similar to holographic recording, or in the case of surface relief holograms, by embossing. Surface relief holograms are recorded in photoresists or photothermoplastics, and allow cheap mass reproduction. Such embossed holograms are now widely used, for instance as security features on credit cards or quality merchandise. The Royal Canadian Mint even produces holographic gold and silver coinage through a complex stamping process[2].

The first step in the embossing process is to make a stamper by electrodeposition of nickel on the relief image recorded on the photoresist or photothermoplastic. When the nickel layer is thick enough, it is separated from the master hologram and mounted on a metal backing plate. The material used to make embossed copies consists of a polyester base film, a resin separation layer and a thermoplastic film constituting the holographic layer.

The embossing process can be carried out with a simple heated press. The bottom layer of the duplicating film (the thermoplastic layer) is heated above its softening point and pressed against the stamper so that it takes up its shape. This shape is retained when the film is cooled and removed from the press. In order to permit the viewing of embossed holograms in reflection, an additional reflecting layer of aluminium is usually added on the hologram recording layer.

Dynamic holography

The discussion above describes static holography, in which recording, developing and reconstructing occur sequentially and a permanent hologram is produced.

There exist also holographic materials which don't 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 µs, 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 [3].

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 to remove 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 the atmospheric turbulence (the phenomenon that gives rise to the twinkling of starlight).

3-8 Electron holography

Electron holography is the application of holography techniques to electron waves rather than light waves. Electron holography was invented by Dennis Gabor to improve the resolution and avoid the aberrations of the transmission electron microscope. Today it is commonly used to study electric and magnetic fields in thin films, as magnetic and electric fields can shift the phase of the interfering wave passing through the sample.

3.9 Acoustical holography

Ultra-high-frequency sound wave (Ultra sound) is used to create the hologram. Laser beam is the used to reconstruct the image. The acoustical hologram helps to record images in dense liquids and solids where light cannot. It can record diverse things under water submarine and internal body organ.

4 APPLICATIONS OF HOLOGRAMS

Holography has today emerged as an important tool in science and technology. It is a well used method to produce pictures and represents one of the most prominent examples of recombining of scattered radiation to produce pictures. This process of producing holograms is now spreading from the research laboratory to various industries, and holograms find wider employment in communication and other engineering problems. A hologram is not only a three-dimensional image but also can store numerous quantities of information. In the computer technology, holograms can be used to store memories which are much larger and faster. Hologram has today become a very well known concept in credit cards, tickets or original covers on software computer programs or any objects to prevent falsification. An important area of application of hologram is bar-code readers in shops, warehouses, libraries etc. A code reader is based on the use of holographic components like optical gratings. Some other examples of the use of holographic technology is in the aircraft industry's head-up displays (HUD) or for making holographic optical elements (HOE) and so on. Let’s see some of them.

4-1 Holographic data storage

Holography can be applied 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 photopolymers. 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.

In 2005, companies such as Optware and Maxell have produced a 120mm 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.

Holographic Optical Element (HOE)

- Can be used for non pictorial purposes like making diffraction gratings
- Consists of fringe system
- Are used inside supermarket checkout scanners that automatically read the bar patterns of the universal product code (UPC) on merchandise
- Are used in heads up display in airplane cockpits, in office copy machines and solar converters.

4-2 Digital holography

An alternate method to record holograms is to use a digital device like a CCD camera instead of a conventional photographic film. This approach is often called *digital* holography. In this case, the reconstruction process can be carried out by digital processing of the recorded hologram by a standard computer. A 3D image of the object can later be visualized on the computer screen or TV set.

4-3 Holography in art

In London, Dalí assembled his models by hanging objects with wires inside of wooden frames. This technique allowed for overlapping and differences in depth. Since then the quality of the holograms has increased dramatically, mainly due to better holographic emulsions. As of 2007 there are many artists who use holograms in their creations.

Holographic interferometry: Microscopic changes on an object can be quantitatively measured by making two exposures on a changing object. The two images interfere with each other and fringes can be seen on the object that reveals the vector displacement. In real-time holographic interferometry, the virtual image of the object is compared directly with the real object. Even invisible objects, such as heat or shock waves, can be rendered visible. There are countless engineering applications in this field of holometry.

Today holographic testing of mechanical systems is a well established practice in industry, serving from noise reduction in automobile transmission to routine jet engine inspections.

It has three approaches:

- Double exposure technique
- Real –time method
- Time average approach

Micro inch distortions in an object resulting from strain, vibration, heat and so on can be studied. It also indicates displacements suffered by an object

4-4 Holograms as diffraction gratings

When holograms are constructed, the reference beam and the object beam interfere with one another, and the dark and light fringes of the interference pattern are recorded. The clear, light parts become like the slits of a diffraction grating, and the angle at which they bend incoming light (the reconstruction beam) is determined by the spacing between them, which in turn was determined originally by the object beam and reference beam, when the hologram's interference pattern was made.

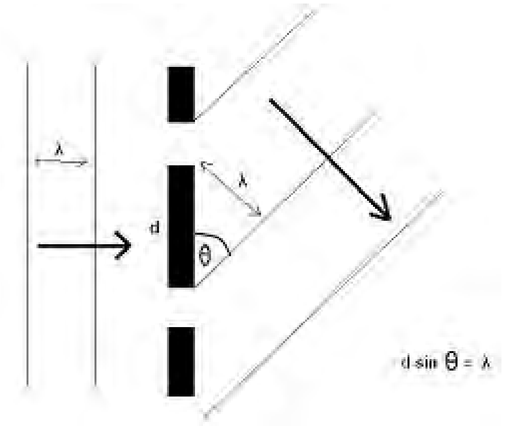


Fig. 4.1 a diffraction grating receives incoming light from the left which is diffracted by the slits

The destructive interference leaves behind slits that become a diffraction grating. The incoming light is bent by them.

All objects that we see, we see as a collection of point sources. Each point on the object radiates out light as a point source and the collection of points our eyes see becomes a whole object. It is the same with holograms: every single point on the object records its own private interference pattern, which gets individually reconstructed, and our eyes see all these points reconstructed together to see the whole picture of the hologram all at once.
This explains why our view on the object in the hologram changes with our position; each time we move we are seeing a different ray emitted from each point source. With normal photography, the camera records just one view, so when you move you are in effect seeing the same ray again and your view doesn't change. (You are seeing different rays from each dropet of ink, but each droplet of ink is one ray of the picture.) The hologram, in comparison, records every possible view there is to see, all at once.

4-5 In health sector

Recent improvements in hologram recording techniques and the availability of tools for the interpretation of holographic interferograms and the success of holographic techniques in imaging through tissues, ophthalmology, dentistry, urology, otology, pathology, and orthopedics shows a strong promise for holography to emerge as a powerful tool for medical applications. Holographic 3D images of eyes and interferometric testing of human teeth and chest motion during respiration were carried out quite early.

X-ray holography can be applied for imaging of internal parts of the body and living biological specimens with very high resolution without the need for sample preparation. Endoscopic holography has opened up the possibility of noncontact high resolution 3D imaging and nondestructive measurements inside the natural cavities of internal organs.

Endoscopic Holography Endoscopic holography has potential of providing a powerful tool for non contact high resolution 3D imaging and nondestructive measurements inside natural cavities of human body or in any difficult to access environment. It combines the features of holography and endoscopy.

4-6 In military

Battle Simulation and Scenarios can be played in advance so that every possible contingency can be calculated.

Holograms are a valuable tool on the battlefield itself also, consider Holographic Decoys and Deception Applications - deception tactics are extremely important in wartime. Better yet just the fact that you have these technologies makes the enemy second guess you and hesitate and the way that wars are fought now at light speed, that is an extreme advantage.

Many new soldiers are not quite prepared for the reality of war and the gruesome sights they will see, which often leave psychological and emotional scares. With Holographic Imaging the soldier can be toughened up prior to battle using hologram Virtual Reality Training and Mind Conditioning equipment.

Tele-Presence in Command and Control Communication also will be a major military application of holographic technology. Instead of mere, voice or video, specially coded holographic communication will rule the day.

In technology

- **Holographic TV** is not a very used product today but with advancement of technology it is no doubt that 3D hologram TV is sure to be an essential commodity in every one’s home.
- **Holographic glasses** have digital computer generated hologram lenses. With 3D effect make 3D films work worthy. Generally have the ability to generate diffractive elements in the form of binary amplitude and binary phase.

We can generalized the uses of holograms in the following way that holograms:

- ✓ Combat counterfeiting (forgery)
- ✓ Cannot be reproduced except from their original master.
- ✓ Provide authentication (many manufacturers use embossed holographic seals to identify authenticity)
- ✓ Enhance packaging appeal and increase brand sales.
- ✓ Minimize document tampering(from being damage)

Holographic elements are now utilizes in packaging products such as sporting goods and merchandises.

Holography has been increasingly used for brochures and magazines.

Here are some pictures that shows application of holography.

Seal on passports

3D TV

Holographic eye

glass stickers

CONCLUSION

Summary and Conclusion

A typical holographic system consists of laser source, diverging senses to increase the beam size, mirrors to change the direction of the source beam and photosensitive film or plate to record the image in the form of interference patterns. Once the patterns are formed on the transmission hologram one cannot see the image which needs reconstruction by illuminating the plate from the back with the reference beam.

In this project basic concepts and applications of holography are presented. Models and results are described in a simple form. The reader can find more details about theoretical and experimental parts. Holographic system or technique requires patience of the user.

The author recommends to the ministry of Education curriculum developers that since nowadays holography id applicable in all fields and contributing a lot for the advancement of science and technology, in research areas for security purpose etc. it should be included as a sub topic in preparatory level physics curriculum and can be exercise in high school physics laboratories.

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