Technical University of Lodz

Department of Semiconductor of Optoelectronics Devices

Laboratory of Optoelectornics

Instruction 5

Analysis of optical phenomena using the Laser Kit.

1. Goal

In this exercise students can analyze basic optical phenomena such as interference, diffraction and holography using a visible light source and a set of mirrors, lenses etc.

2. Theory

Interference is the phenomena in which two waves (electromagnetic or mechanical, de Broglie etc.) superpose each other and as a resultant of it we get wave of greater or lower amplitude. The amplitude of the resulting wave in each point is given by the formula:

$$A = \sqrt{A_1^2 + A_2^2 + A_1 \cdot A_2 \cos\phi}$$

where:
A_1, A_2 - partial wave amplitude
φ - the phase difference between two waves.

Consider two waves that are in phase, sharing the same frequency and with amplitudes A_1 and A_2. Their troughs and peaks line up and the resultant wave will have amplitude $A=A_1+A_2$. This is known as constructive interference and it occurs for $\varphi=2k$. If the two waves are π radians, or 180°, out of phase, then one wave's crests will coincide with another wave's troughs and so will tend to cancel out. The resultant amplitude is $A = |A_1-A_2|$; and if $A_1=A_2$, the resultant amplitude will be zero. This is known as destructive interference and it occurs for $\varphi=(2k+1)$.

Interference usually refers to the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency.

Michelson interferometer:

This interferometer consists of two highly polished mirrors M_1 and M_2. A source S emits monochromatic light that hits a half-silvered mirror, surface M, at point C. M is partially reflective, so one beam is transmitted through to point B while one is reflected in the direction of A. Both beams recombine at point C to produce an interference pattern (assuming proper alignment) visible to the observer at point E. To the observer at point E, the effects observed would be the same as those produced by placing surfaces A and B' (the image of B on the surface M) on top of each other. Let's look at this interaction in more detail.
Imagine that we have two surfaces - M_1 and M_2 – placed as it is shown in Fig. 2. There are two paths from the laser light source to the detector. One reflects off the semi-transparent mirror, goes to the top mirror and then reflects back, goes through the semi-transparent mirror, to the detector. Second path starts when beam goes through the semi-transparent mirror, to the mirror on the right, reflects back to the semi-transparent mirror, then reflects from the semi-transparent mirror into the detector.

The principle is when a parallel beam of light coming from a monochromatic extended light source is incident on a half silvered (semi-transparent) glass plate, it is divided into two beams of equal intensities by partial reflection and transmission. Both beams are coherent. In this experiment coherent waves are thus produced by the method of division of amplitude.

Light diffraction:

It is a property of "wave motion" – in which waves spread and bend as they pass through small openings or around barriers. The principle of light diffraction can be explained by Huygens" Theory. He proposed that when a wave of light passes through an aperture or around a barrier every point of it acts like a secondary wave source. These waves then travel different paths and subsequently interference with each other. A typical diffraction pattern can be obtained by inserting a screen into the interference field.

One of the simplest example of light diffraction occurs when a parallel beam of light (eg from a laser) passes through a narrow gap called single diffraction gap. According to Huygens' principle each point of the gap width d, is a new source of waves. Between sources we can observe the interference which cause the strengthening and weakening of the light emitted in different directions. For a single gap brightness as a function of the angle of deviation is given by the formula:

$$I(\theta) = I_0 \left[\mathrm{sinc} \left(\frac{\pi d}{\lambda} \sin \theta \right) \right]^2,$$

where:
- I – light intensity,
- I_0 – light intensity in maximum (when $\theta = 0$)
- λ – wavelength,
- d – gap width,
- function $\mathrm{sinc}(x) = \sin(x)/x$.

Holography:

Holograms are recorded on special photographic material. The interference field of both the object and the reference waves is recorded. The object wave is reflected by and object and the reference wave is usually a planar one. The object wave carries information about the recorded object. If this wave were recorded without any reference wave, only amplitude record, normal photography would be obtained. When a reference wave is present a phase record occurs. Such a record is able to save information about the spatial relations of the object. The diffraction field of the object and the reference wave is recorded and photochemically processed. An optical grating is obtained on which light can diffract.

3. Exercise

Light interference:

You will need: laser, ground screen, glass plate, frame holder, lens.
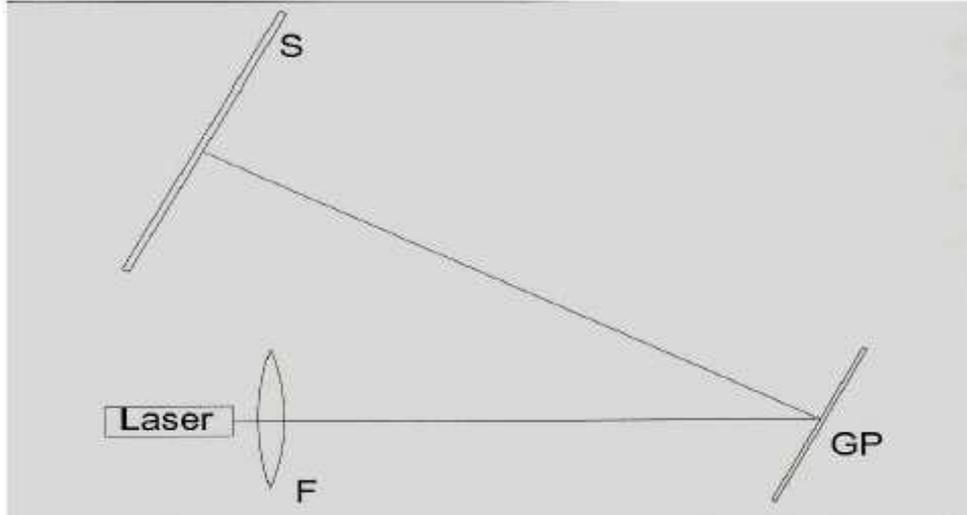
Procedure:

Fig. 1 The experimental set-up scheme for demonstration of interference of light waves reflected from a thin glass plate: F-lens, GP-glass plate, S-ground screen

1. Arrange the elements as shown in the picture.
2. Put on the lens on the laser and observe the interference pattern.

Michelson interferometer:

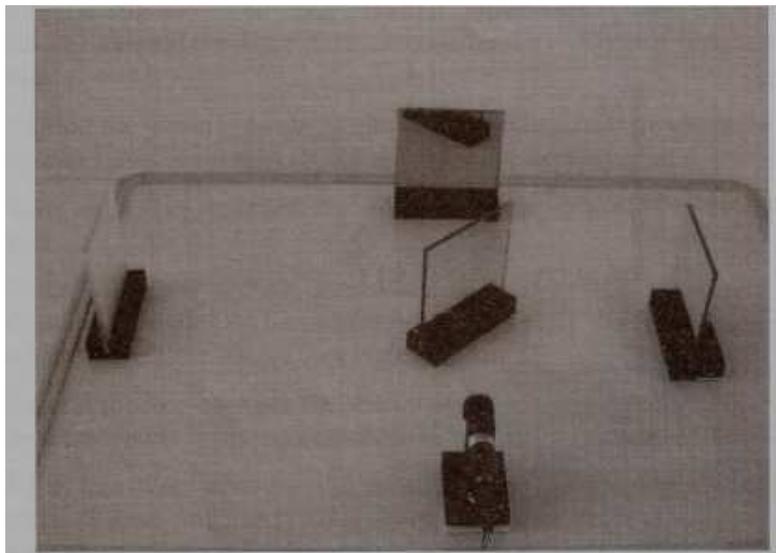You will need: laser, ground screen, 2 mirrors, 1 semi-transparent mirror, lens.

Fig. 2 Michelson interferometer.

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Procedure:
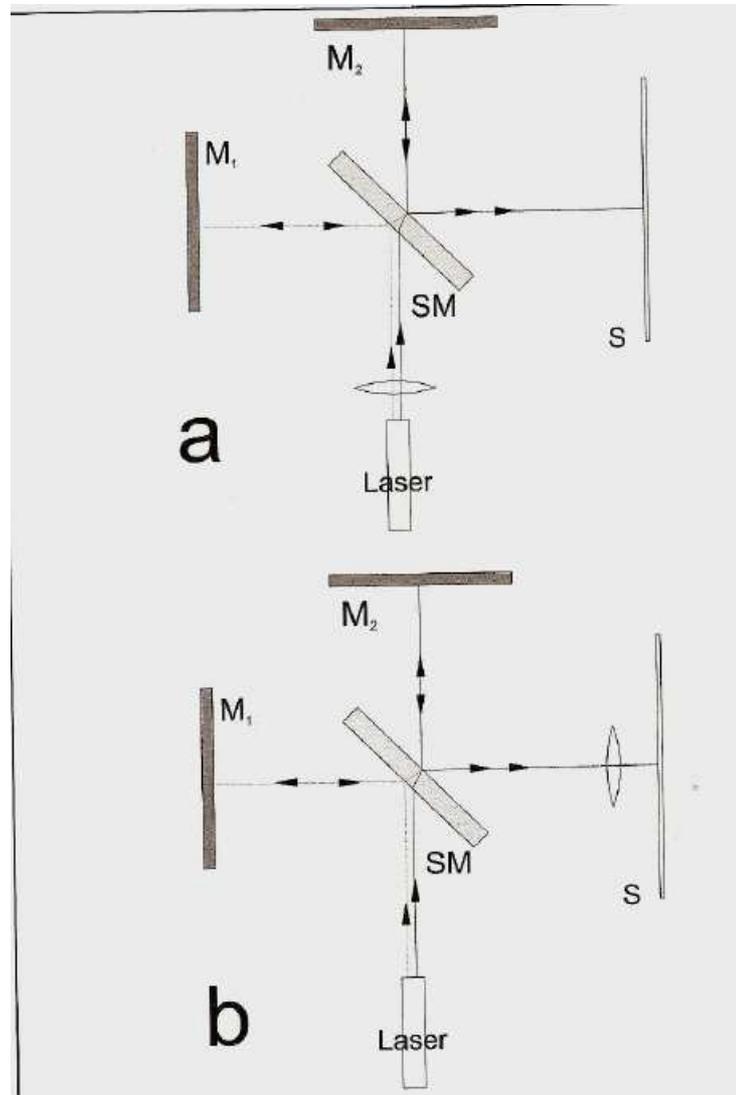
1. Arrange the elements as shown in the picture.

Fig. 3 The scheme of Michelson's interferometer M₁, M₂ – mirrors, SM – semitransparent mirror, S –
ground screen, F- lens

Connect the spots on the screen by moving mirror M$_1$ slightly and adjusting the screw on the mirror holder and place the spots on the same height as the laser source. Position the lens between the semi-transparent mirror and the laser. This causes a typical interference pattern to appear. If the lens were between the ground screen and the semi-transparent mirror (picture below) parallel interference fringes would be observed.

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Light diffraction:

You will need: laser, ground screen, square and circular apertures, frame holder.

Procedure:
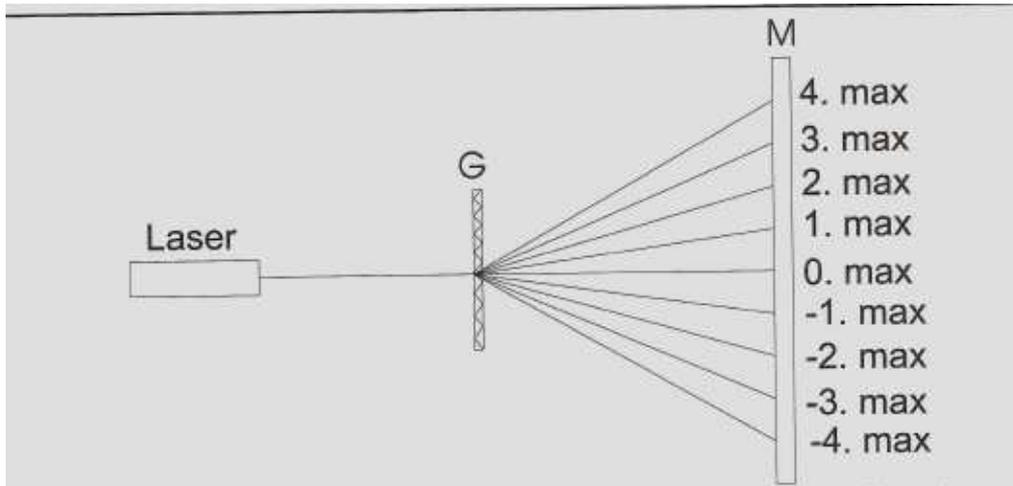
1. Arrange the elements as shown in the picture.

Fig. 3 the diffraction set up scheme. G-diffraction medium (square aperture, circle aperture, grating), M-ground screen

The distance between the aperture and the screen should be at least 50cm. Observe the diffraction patterns by using different apertures.

Holography:

You will need: laser, lens, hologram.

Procedure:

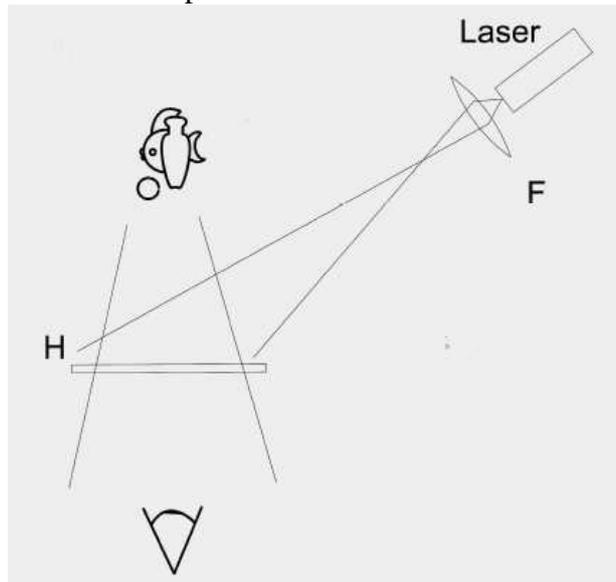1. Arrange the elements as shown in the picture.

Fig. 4 Set-up for hologram reconstruction. F-laser, S-lens, H-hologram.

Observe the hologram at an angle of approximately 30 degree. Rotate the hologram plate slowly until a holographic image appears.

4. Raport

The report shall contain the conclusions of the exercise. When it is possible take a picture of experiments and put them in the raport.