LEOI-22 Precision Interferometer

Instructional Manual

Lambda Scientific Systems, Inc

14055 SW 142nd Avenue, Suite 22, Miami, FL 33186, USA
Phone: (305) 252-3838; Fax: (305) 517-3739
E-mail: sales@lambdasys.com; Web: www.lambdasys.com

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COMPANY PROFILE

Lambda Scientific Systems, Inc. specializes in developing and marketing scientific instruments and systems designed and manufactured specifically for experimental education in physics at colleges and universities. Our mission is to become a premier supplier of high-quality, robust, easy-to-use, and affordable scientific instruments and systems to college educators and students for their teaching and learning of both fundamental and modern experiments in physics. Our products focus on comprehensive physics education kits, spectroscopic instruments, as well as light sources and opto-mechanical components.

Our physics education kits cover a wide range of experiments in general physics, especially in geometrical optics, physical optics, and fiber optics. Experiments include lens imaging, interferometry, diffraction, holography, polarization, laser physics, quantum optics, and Fourier optics through a series of the most representative apparatus such as Newton's ring apparatus, Young's modulus apparatus, Michelson interferometer, Fabry-Perot interferometer, Twyman-Green interferometer, Fourier spectrometer, and laser.

Our fiber optics education kits keep a pace with the advent of fiber optical communication technology by designing experimental systems to teach fundamental optical fiber concepts such as fiber-to-fiber coupling, fiber-to-source coupling, fiber numerical aperture, fiber mode, fiber transmission loss, and fiber sensing. These kits also give students an opportunity to be familiar with modern fiber optic components or apparatus such as Mach-Zehnder interferometer, variable optical attenuator, fiber isolator, fiber splitter, fiber switch, wavelength-division multiplexer, fiber amplifier, and transmitter.

Our spectroscopic instruments cover various general-purpose spectrometers/ spectrophotometers such as UV/Vis spectrophotometers, laser Raman spectrometer, dual-beam IR spectrophotometer, FT-IR spectrometer, CCD spectrometer and monochromators. We still provide specially designed spectroscopic experimental systems for teaching purpose of demonstrating physical principles of spectroscopic instruments such as modular multifunctional spectrometers and experimental Fourier transform spectrometer.

Our light sources include Xenon lamp, Mercury lamp, Sodium lamp, Hydrogen lamp, Hydrogen-Deuterium lamp, Bromine Tungsten lamp and various lasers.

We also provide a variety of opto-mechanical components such as optical mounts, optical breadboards and translation stages. Our products have been sold worldwide. Lambda Scientific Systems, Inc is committed to providing high quality, cost effective products and on-time delivery.

CONTENTS

1. Introduction

The Michelson interferometer is known for observing two-beam interference phenomena such as equal-inclination interference, equal-thickness interference, and white-light interference. It has been used for precise measurements of wavelengths, small-path distances, and refractive indices of transparent media. The Fabry-Perot interferometer is used for observing multiple-beam interference and measuring fine spectral structures (e.g. wavelength disparity of yellow sodium doublet lines). The Twyman-Green interferometer is used to measure the defects in optical components such as lenses, prisms and windows etc.

This equipment kit can be easily switched between Michelson, Fabry-Perot, and Twyman-Green Interferometer configurations. Its main application is for experimental demonstration in physics at universities, colleges, and other academic institutions.

2. Specifications

Flatness of Beam Splitter & Compensator Plate	0.1λ
Minimum Travel Reading	0.25 μm
Travel of Moving Mirror	0.625 mm (travel of fine micrometer: 25 mm)
Sodium-Tungsten Lamp	Sodium: 20 W; Tungsten:15 W
He-Ne Laser	0.7 ~ 1 mW at 632.8 nm
Overall Dimension	350 mm×350 mm×245 mm
Weight	Approx. 35 Lbs

List of Parts

No.	Description	Specification	Qty
1	Main interferometer		1
2	Ground glass screen	Φ50 mm	1
3	Extension arm		1
4	He-Ne laser	0.7~1 mW	1
5	Laser holder		1
6	Sodium-Tungsten lamp	Sodium: 10 W, Tungsten: 15 W	1
7	Air chamber and pump with gauge	Range: 0~40 kPa; Chamber length: 80 mm	1
8	Two-in-one screen		1
9	Transparent slice clip		1
10	Beam expander		1
11	Samples	Slice surface of different quality	2
12	Alignment hole on post	For optical alignment	1
13	Thumb screw	For locking the posts of laser holder or the Sodium-Tungsten lamp on the side stage, or for mounting the extension arm to corresponding sockets on the main stage.	2
14	Manual counter	4 digits, counts 0 ~ 9999	1
15	Power cord		2

3. Theory

3.1 Interference

Light is an electromagnetic wave associated with electric and magnetic fields. When two or more light waves overlap, the total light wave at any point and at any instant is governed by the law of superposition. As a result, the resultant electric or magnetic field at any point and at any instant is the addition of the instantaneous electric or magnetic fields produced at the point by the individual light waves. If the individual light waves have phases that bear no fixed relationship to each other over time, then the strength of the added electric or magnetic field at a point would vary randomly over time. Such strength, if averaged over time, would become more or less identical at all points on an observation screen. Under such circumstances, the screen would be more or less uniformly illuminated and an interference pattern would not be seen on the screen. These sources are called as incoherent sources.

By contrast, coherent sources are those whose output waves maintain a constant phase relation to each other over time. Usually, these light waves come from the same source so that they bear some degree of frequency and phase correlation between them. When the light waves from two coherent sources arrive at a point in phase, the field of the resultant wave is the sum of those of the individual waves; thus the individual waves reinforce each other, known as constructive interference. When the two coherent waves arrive at another point out of phase, the field of the resultant wave is the difference of those of the individual waves; hence the individual waves undermine each other, named as destructive interference. Thus, an interference phenomenon is observed only when the sources are coherent.

Light wave interference from two sources was first demonstrated by Thomas Young in 1801. Young designed an apparatus to allow a plane light wave to fall on two closely spaced parallel slits, serving as a pair of coherent light sources as waves emerging from them originate from the same wave front and therefore maintain a fixed phase relationship. The light from these two slits produces a visible pattern of bright and dark parallel bands called fringes on a viewing screen. Young's experiment obtained convincing evidence for the wave nature of light.

3.2 Michelson Interferometer

An important instrument involving wave interference is the Michelson interferometer invented by A. A. Michelson in 1881 using a similar principle. Now, Michelson interferometers have been used to measure wavelengths or other lengths with great precision.

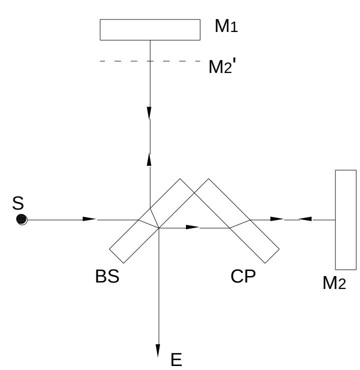


Figure 1 Diagram of the Michelson interferometer

Figure 1 shows the schematic of a Michelson interferometer. A ray of light from a monochromatic source **S** is split equally into two rays by a beam-splitter **BS**, which is inclined at 45° to the incident light beam. One beam is reflected by **BS** vertically upward toward a fixed mirror $\mathbf{M_1}$, the second ray is transmitted horizontally through **BS** toward a movable mirror $\mathbf{M_2}$. After reflecting from $\mathbf{M_1}$ and $\mathbf{M_2}$, the two rays eventually recombine at **BS** to produce an interference pattern, which can be viewed by an observer's eye **E**. The purpose of using a compensator plate **CP** here is to ensure that the two rays pass through the same thickness of glass, as **CP** is cut from the same piece of glass as **BS** so that their thicknesses are identical.

The interference condition for the two rays is determined by their path differences. In general, the interference pattern is a target pattern of bright and dark circular fringes. As $\mathbf{M_2}$ is moved, the fringe pattern collapses or expands, depending upon the moving direction of $\mathbf{M_2}$. In either case, the fringe pattern shifts by one-half fringe each time $\mathbf{M_2}$ is moved a distance that is equal to a quarter of the wavelength of light. As a result, the wavelength of light can be measured by counting the number of fringe shifts for a given displacement of $\mathbf{M_2}$. On the other hand, if the wavelength of light is known, mirror displacement can be measured precisely, within a fraction of the wavelength of light using the same procedure.

3.3 Fabry-Perot Interferometer

When one beam of light passes through a plane-parallel plate with two reflecting surfaces, it is reflected many times between the two surfaces and hence multiple-beam interference occurs. The higher the surface reflectance is, the sharper the interference fringes are. That is the basic principle of the Fabry-Perot interferometer.

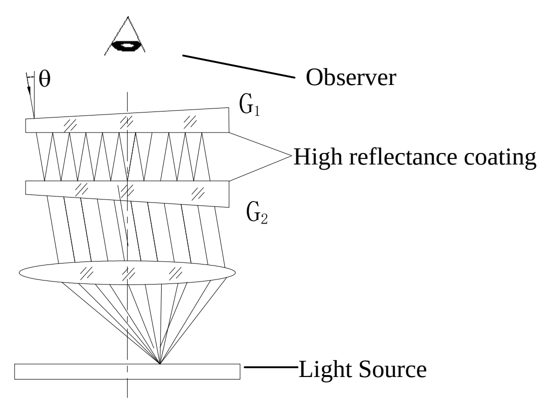


Figure 2 A schematic Fabry-Perot interferometer

As shown in Figure 2, two partially reflecting mirrors $\mathbf{G_1}$ and $\mathbf{G_2}$ are aligned parallel to each other, which form a reflective cavity. When monochromatic light is incident on the reflective cavity with an angle θ, many parallel rays pass through the cavity to become the transmitted light. The optical path difference between two neighboring rays is given by δ:

$$\delta = 2nd\cos\theta$$

Thus, the transmitted light intensity is:

$$I' = I_0 \frac{1}{1 + \frac{4R}{(1-R)^2}\sin^2\frac{\pi\delta}{\lambda}}$$

where I_0 is the incident light intensity, R is the mirror reflectivity, n is the refractive index of the medium in the cavity, d is the cavity length or mirror spacing, and λ is the wavelength of the monochromatic light.

Thus, I' varies with δ. When

$$\delta = m\lambda \qquad (m = 0, 1, 2\ldots)$$

I' becomes a maximum so that constructive interference of the transmitted light occurs; when

$$\delta = (2m' + 1)\lambda/2 \qquad (m' = 0, 1, 2\ldots)$$

I' becomes a minimum and destructive interference of the transmitted light is observed.

3.4 Twyman-Green Interferometer

Twyman-Green interferometer is a variant of the Michelson interferometer and it is mainly used to measure the defects in optical components such as lenses, prisms, windows, laser rods, and plane mirrors. Although the beam splitter and mirror arrangement in a Twyman-Green interferometer resembles a Michelson interferometer, there is a difference between these two interferometers. That is the light source used in a Michelson interferometer is usually an extended source (though it can also be a laser), while a Twyman-Green interferometer always uses a point light source such as a laser. The quality of an optical component under test can be evaluated from the irregularities of the interference pattern caused by placing the component into one beam path of a Twyman-Green interferometer. In particular, spherical aberration, coma, and astigmatism can be identified as specific variations in the fringe pattern.

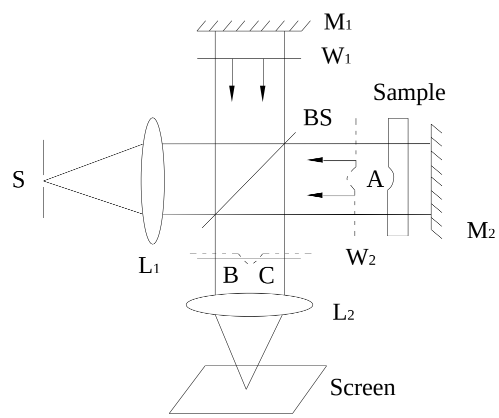
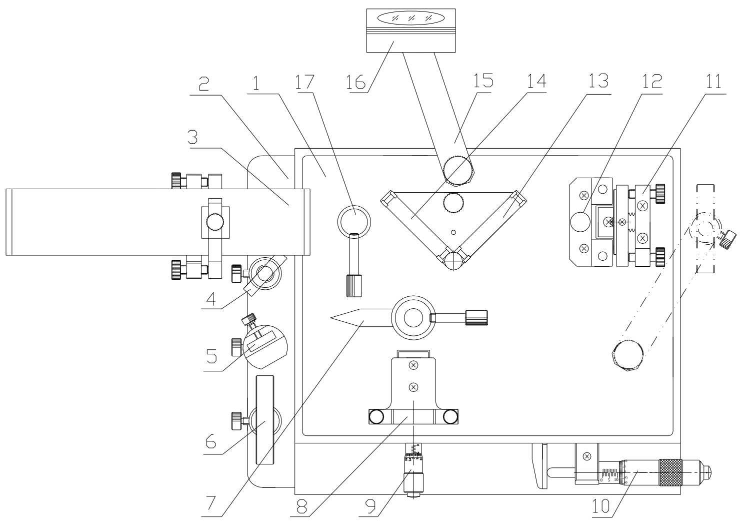


Figure 3 Schematic of Twyman-Green interferometer

In above figure, if the sample under test has perfectly flat surfaces, then the returning wave front is plane and no fringes are observed. However, if the optical flat is not perfectly flat on either side, the wave from M2 returning to the beam splitter is no longer plane. Thus, the phase difference between the superimposed waves of M1 and M2 will vary across the field of view and a fringe pattern will appear. These fringes form a contour map of the distorted wave front, so that the imperfections of the sample are displayed in terms of wave front aberrations.

4. Structure

This equipment combines a Michelson interferometer, a Fabry-Perot interferometer, and a Twyman-Green interferometer on one base made of a thick steel plate with a rigid-frame.



1. Main stage
2. Side stage
3. Light source (He-Ne laser or sodium-tungsten lamp)
4. Beam expander
5. Transparent slice clamp
6. Ground glass screen
7. Rotational pointer and SOCKET3
8. Fixed Mirror (It is also used as a F-P mirror)
9. Presetting micrometer
10. Fine micrometer
11. Movable mirror
12. Stage with mounting holes for 6 and 8
13. Compensator
14. Beam splitter
15. Extension arm
16. Two-in-one screen
17. SOCKET2 for beam expander

Figure 4 Layout diagram of the instrument

The layout of the equipment is seen in Figure 4. On side stage (2), there are one extruded hole for installing light sources (He-Ne laser or Sodium-Tungsten lamp) and three small holes for holding other items such as beam expander (4), transparent slice clamp (5) and ground glass screen (6). Beam expander is installed in SOCKET2 (17) when in use. Fixed mirror (8) is the reference mirror of the Michelson interferometer and can be used as the front mirror of the Fabry-Perot interferometer. Beam splitter (14) is coated with semi-permeable film on the inner side. Compensator (13) has the same thickness as beam splitter (14) and is at 90° angle to (14). The relative positions of beam splitter and compensator have been adjusted before leaving the factory and they do not need to be readjusted by the user. Movable mirror (11) is controlled by fine micrometer (10) which has a travel of 25 mm. When the fine micrometer moves 0.01 mm (resolution), then the movable mirror moves by 0.00025 mm, relative to the main stage. A ground glass screen is used to observe the fringes of the Michelson interferometer, with eye protection from the laser light.

5. Operation of Experimental Examples

5.1 Michelson Interferometer

5.1.1 Interference Fringe Observation

<u>He-Ne laser as the light source</u>

Warning:
a) Direct eye exposure to laser is prohibited.
b) <u>DO NOT</u> observe the laser interference fringes using a reflecting mirror.
c) All experiments should be conducted under low-light conditions for better observation of interference phenomena.

1) Place the laser mount with a He-Ne laser mounted in the mounting hole on the side stage and turn on the laser power.
2) Place beam expander in SOCKET2. Adjust the height of the laser tube to make the beam hit the center of the beam expander. Then remove the beam expander.
3) Observe the beam spot on the beam splitter; it should be approximately in the middle of the beam splitter. Also observe the beam spot on the movable mirror. Adjust the laser tube to make the beam spots on beam splitter and movable mirror at the same height.

   Note: This may involve tilting the tube and so remember to re-adjust the height each time tilting occurs. Place a piece of paper card (e.g. Business card) in front of the fixed mirror to avoid multiple reflections.
4) Place a piece of paper card in front of the movable mirror.
5) Place the two-in-one screen in the extension arm in SOCKET1 and let the white screen face towards the beam splitter. A beam spot should be seen on the screen, which is reflected from the fixed mirror. There are also other spots on the screen with less brightness due to multiple reflections. Align the white screen until the brightest beam spot is seen on the center of the screen.

Figure 5 Michelson interferometer with He-Ne laser as light source

6) Remove the cards and observe the white screen. Two bright spots should appear (and less bright multiple reflections). Adjust the movable mirror until the two bright spots coincide with each other at the center of the white screen.

7) Position the beam expander into SOCKET2 with the lens lock facing the beam splitter. If the expanded beam spot is not immediately incident on the movable mirror, then adjust the laser tube. The fringe pattern can be observed on the white screen.

   Note: When adjusting the expanded beam spot, hold a piece of paper behind the movable mirror to identify the location of the beam spot. Adjust the two tilting screws on the laser holder to move the spot onto the movable mirror.

If the observed fringes are not circular, or they are smaller than you may expect, then adjust the presetting micrometer to 'zoom' in or out to get a better view. If no fringes are observed, then repeat the instructions from the beginning; otherwise contact sales@lambdasys.com for technical support.

<u>Sodium lamp as the light source</u>

Figure 6 Michelson interferometer with Sodium lamp as light source

1) Remove the He-Ne laser and beam expander. Place Sodium-Tungsten lamp in the mounting hole (only the Sodium lamp is turned on at this moment).

2) Flip the two-in-one screen to view the interference pattern on the mirror side. Adjust the height of the lamp, so that the sodium light strikes at the center of the mirror. Generally, interference fringes can be observed from the reflected light.

   Note: If fringes are not observed, it means that the interference light path has changed due to vibration when replacing the light source. To retrieve the fringes, the following processes should be taken.

3) Place a pinhole (you can pierce a hole on a business card) in front of the lamp and adjust the movable mirror until the two images of the pinhole coincide with each other.

4) Remove the pinhole and interference fringes should be observed by viewing the mirror. Using the ground glass screen is optional in this experiment, but if in use, it should be inserted between the light source and the beam splitter (SOCKET2).

5.1.2 Equal-Inclination Interference

Now let's study a different kind of fringes produced by a Michelson interferometer. As shown in Figure 7**,** $\mathbf{M_2}$**'** is the virtual image of movable mirror $\mathbf{M_2}$**.** In the observer's field of view, it seems that the two light beams were reflected from mirrors $\mathbf{M_1}$ and $\mathbf{M_2}$**'** and the interference pattern were produced by a thin air film between $\mathbf{M_1}$ and $\mathbf{M_2}$**'**.

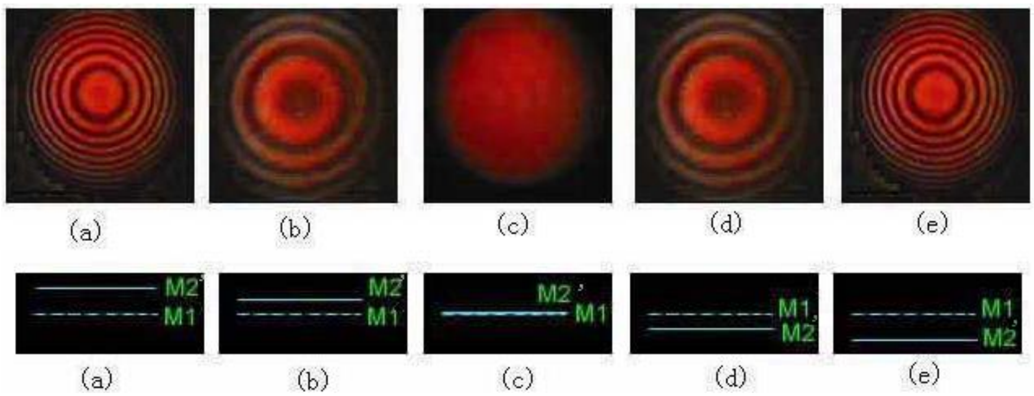


Figure 7 Illustration of equal-inclination interference

He-Ne laser as the light source

1) Re-produce the interference image as per 5.1.1, which should be similar to (a).
2) Adjust the coarse micrometer so that images (a) to (e) are viewed in succession.
3) Set the fine micrometer to the middle of the scale (between 10 mm to15 mm).
4) Re-adjust the coarse micrometer as closely as possible to reproduce image (c).
5) Use the fine micrometer to produce fringes of equal inclination.

5.1.3 Equal-Thickness Interference

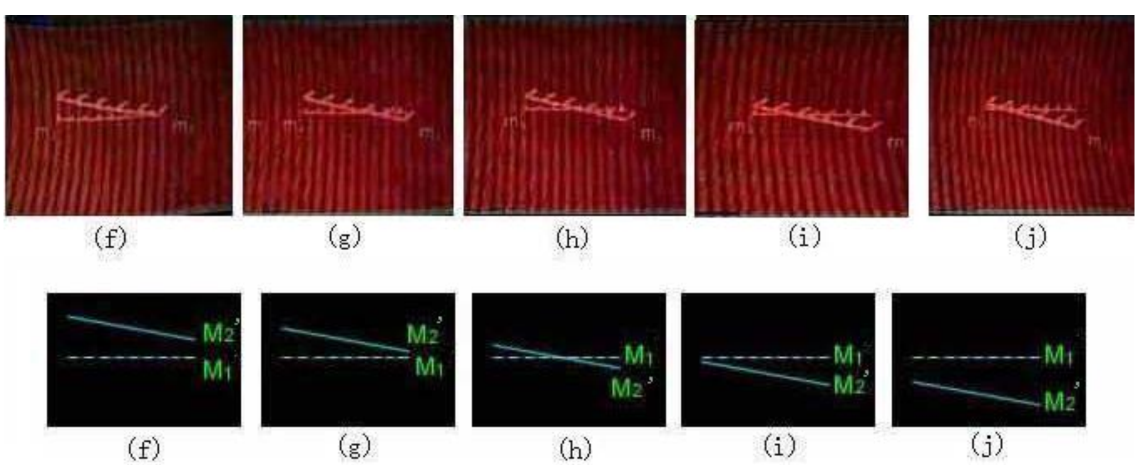


Figure 8 Fringes of equal thickness

Adjust the tilt screws at the back of $\mathbf{M_2}$. If $\mathbf{M_1}$ and $\mathbf{M_2'}$ are tilted with a very small angle with each other, the fringes of equal-thickness interference can be observed on the screen.

He-Ne laser as the light source

1) Install the He-Ne laser and remove the beam expander. Set the fine micrometer to the middle of the scale (between 10 mm to15 mm).
2) Adjust the laser and movable mirror to get interference pattern on the white screen.
3) Turn the coarse micrometer in the direction which interference rings collapse at the center, and then the fringes expand. Stop when there are only a few fringes on the screen.
4) Turn the fine micrometer to move the movable mirror in the direction which interference rings collapse at the center, until there are only two or three rings left.
5) Adjust the movable mirror slightly. If the image of movable mirror M_2' is tilted relative to the fixed mirror M_1, interference stripes should be observed.
6) Continue to turn the fine micrometer to make the curved fringes move toward their center. Some straight bands will appear in succession. Those are the fringes of equal-thickness interference.

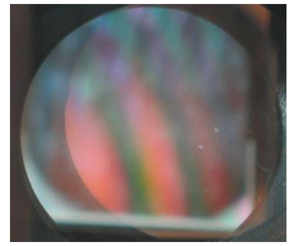
5.1.4 White-Light Interference Fringes

Because white light has a short coherence length, interference fringes from white light can only be observed when the optical-path difference is close to zero. Compared to the interference pattern created by a laser or a Sodium lamp, white light interference is much more difficult to produce. With the help of a specially designed Sodium-Tungsten lamp, zero path difference can be easily obtained for the observation of white-light interference.

Figure 9 Michelson interferometer with Sodium-Tungsten lamp as light source

1) After achieving equal-inclination interference (5.1.2), replace the laser with the Sodium- Tungsten lamp and remove the beam expander. Use the mirror of the two-in-one screen as the observation screen.

2) Adjust the height of the light source until the yellow Sodium light and white Tungsten light illuminate the upper and lower half of the viewing field, respectively. Make sure that the visible Sodium fringes have good contrast and wide-spacing. Interference fringes of Sodium doublet may help locate the point of zero path difference.



Note: If no fringes are observed, it means that the interference light path has changed due to vibration when replacing the light source. To retrieve the fringes, the following processes should be taken.

3) Place a pinhole (you can pierce a hole on a business card by a pin) in front of the lamp and adjust the movable mirror until the two images of the pinhole coincide with each other. Now interference fringes should be seen in the viewing mirror.
4) To search for white light fringes, turn the fine micrometer slowly to maintain the yellow fringes in the field of view. Otherwise, the condition of zero path difference and hence the production of white light fringes might be missed if the fine micrometer were turned too fast.
5) This way color fringes will continue to appear, and at a moment, an interference fringe pattern with a dark center will be observed. That is the white-light interference at the position of zero light-path difference.
6) To observe the white-light interference fringe clearly, the Sodium lamp should be turned off and the ground glass screen should be put in SOCKET2.

5.1.5 Measurement of the Wavelengths of the Sodium D-lines

Figure 10 Michelson interferometer with Sodium-Tungsten lamp as light source

1) Place the Sodium-Tungsten lamp on the side-stage and warm it up for about 5 minutes.
2) Adjust the interferometer to produce circular fringes in the field of view.
3) At the position with a clear equal-inclination fringes, record the reading d_0 of the fine micrometer.

4) Count the number of fringes that expand (or collapse) in the center of the field of view as the fine micrometer is turned slowly (using the provided hand tally counter). After counting 50 fringes, record the micrometer reading again.

5) Continue the above process through 250 fringes, and record the micrometer reading after each set of 50 fringes has been counted. Calculate the actual mirror movement, Δd , as

$$\Delta d = \frac{\Delta N \lambda}{2}$$

where λ is the wavelength of the source and ΔN is the number of fringes counted. On the other hand, the wavelength of the source can be determined by

$$\lambda = \frac{2\Delta d}{\Delta N}$$

Alternatively, one can plot Δd vs ΔN, and conduct linear curve-fitting to the data, the fitted slope is $\lambda/2$.

Notice:

a) Always turn the micrometer knob in one direction.

b) Set the micrometer screw somewhere near the middle of its travel. In this position, the relationship between the micrometer reading and the mirror movement is nearly linear.

c) Turn the micrometer a full turn before counting fringes to eliminate backlash errors.

5.1.6 Measurement of the Wavelength Separation of the Sodium D-lines

The Michelson interferometer can also be used for measurement of the wavelength separation of the Sodium D-lines. The yellow Sodium doublet consists of two spectral lines with a small wavelength separation between them. Therefore, when a Sodium lamp is used as the light source in a Michelson interferometer, the interference fringes produced by two yellow lines will appear periodically (clear and blurry) as the movable mirror is moved continuously. The wavelength difference of the yellow sodium doublet lines is given by

$$\Delta\lambda = \frac{\bar{\lambda}^2}{2\Delta d}$$

Where $\bar{\lambda}$ is the averaged wavelength of the two lines through the result of last experiment, Δd is the thickness of the air membrane between mirrors $\mathbf{M_1}$ and $\mathbf{M_2'}$.

1) Adjust the interferometer to obtain a clear, wide-spaced interference pattern of Sodium doublet. Slowly turn the fine micrometer till all the fringes disappear. Record the reading d_1 of the micrometer;

2) Continue to turn the micrometer in the same direction and new interference pattern appears. Record the reading d_2 where the interference pattern vanishes again;

3) Repeat this process in different places near zero path difference point to get an average value of $\Delta d = |d_1 - d_2|$.

5.1.7 The Refractive Index of Air

In Michelson interferometer mode, if an air chamber is placed in the light path of **M_2** and then the air density in the chamber is altered by deflating or pumping the air in the chamber, the optical-path length will change by δ . Accordingly, a certain number of interference fringes will pass through the viewing point.

$$\delta = 2\Delta n l = N\lambda$$

Therefore,

$$\Delta n = N\lambda / 2l$$

Where, l is the length of the air chamber, λ is the wavelength of the light source, N is the number of fringes counted to pass through the viewing point.

The refractive index of air is dependent upon its temperature and pressure. If n is near unity, then n-1 is directly proportional to density ρ of the gas. For ideal gas:

$$\frac{\rho}{\rho_0} = \frac{n-1}{n_0-1}$$

If T is the absolute temperature, P is the pressure. Then,

$$\frac{\rho}{\rho_0} = \frac{PT_0}{P_0T}$$

Thus,

$$\frac{PT_0}{P_0T} = \frac{n-1}{n_0-1}$$

If the temperature is constant, then

$$\Delta n = \frac{(n_0-1)}{P_0}\Delta P$$

Because $\Delta n = N\lambda / 2l$, then

$$\frac{(n_0-1)}{P_0}\Delta P = N\lambda / 2l$$

Therefore

$$n_0 = 1 + \frac{N\lambda}{2l} \times \frac{P_0}{\Delta P}$$

Figure 11 Michelson interferometer with air chamber in optical path

1) Align the interferometer.
2) Adjust the movable mirror $\mathbf{M_2}$ to obtain clear equal-inclination fringes on the center of the white screen using a He-Ne Laser.
3) Put the air chamber with known length l in its holder (for accurate measurement, the end plates of the air chamber must be perpendicular to the laser beam).
4) Pump in air to the chamber and then record the reading of the gauge ΔP .
5) Release the valve and slowly deflate the air in the chamber till the gauge reads zero. During the process, count N (using the provided hand tally counter). The refractive index of air in the experiment is given by,

$$n_0 = 1 + \frac{N\lambda}{2l} \times \frac{P_0}{\Delta P}$$

where P_0 is the atmospheric pressure (101.325 kPa); l=80 mm.

Note: This experiment should be carried out several times in order to get the average.

Notice: To protect the gauge, the reading of the gauge should not be over 40 kpa.

5.1.8 The Refractive Index of Transparent Slice

When a transparent slice is placed in one optical arm of the Michelson interferometer, the light path of this arm changes as the transparent slice rotates. The difference of the light path can be determined by counting the number of the fringes collapsed or expanded. If the entrance light is perpendicular to the end plate of the transparent slice initially, the refractive index of the slice can be measured by counting the number of fringes passed through while rotating the slice. The refractive index of the slice, n , is given by:

$$n = \frac{n_0^2 d \sin^2\theta}{2n_0 d(1-\cos\theta) - N\lambda}$$

Where λ is the wavelength of the light source (the He-Ne laser), n_0 is the refractive index of air, θ is the rotating angle of the slice, d is the thickness of the slice, and N is the number of fringes counted when the slice is rotated by angle θ.

Figure 12 Michelson interferometer with transparent slice in optical path

Experimental Procedure

1) Place the clip for the transparent slice in the mounting hole in SOCKET3.
2) Place the two-in-one screen on the extension arm and adjust the screws at the back of the movable mirror to get a set of clear fringes on the white screen.
3) Mount the transparent slice on the clip. Adjust the clip and the rotational pointer. Make sure that the slice is approximately perpendicular to the optical path.
4) Slowly rotate the clip using the pointer while monitoring the fringes on the screen carefully. During the process, the fringes in the center of the screen will collapse or expand. Stop rotating when the fringes neither collapse nor expand. Now the slice is set perpendicular to the optical path.
5) Adjust the movable mirror to get a set of clear fringes on the screen. Slowly rotate the slice by moving the lever arm. Count the number of fringe transitions as the slice is rotated from its original angle set in step 4 to its new angle (at least 10 degrees). If the rotating angle is θ and the number of fringes counted is *N*, then the refractive index of the slice, n, is given by the equation:

$$n = \frac{n_0^2 d \sin^2\theta}{2n_0 d(1-\cos\theta) - N\lambda}$$

   Where n_0 is the refractive index of air (see Experiment above), λ is the wavelength of the He-Ne laser in vacuum, N is the number of fringe transitions counted, and d is the thickness of the transparent slice (d = 0.1 mm).

6) Repeat steps 4, 5 and 6 three times and calculate the average of *n*.

5.2 Fabry-Perot Interferometer

5.2.1 The Multi-Beam Interference

1) Turn the interferometer 90° to make the Fabry-Perot interferometer facing the observer at the position opposite to the movable mirror (see structure figure in chapter 4).
2) Unscrew the F-P mirror (i.e. Item 8 in Fig. 4), and then mount it in the holes in front of the movable mirror (Item 11). Make the front surface of F-P mirror face towards the movable mirror.
3) Adjust the three screws behind the movable mirror to make sure that the two mirrors are parallel to each other approximately with a distance of about 2 mm.
4) Unscrew the screw on the top of the beam splitter and compensator and remove the whole beam-splitter/compensator assembly. Put it in a safe place (Fixing it in the place of fixed mirror is a good choice).
5) Set up the He-Ne laser in the light path of the Fabry-Perot interferometer. Adjust the laser to make the laser beam hit the center of the F-P mirror. Adjust the top and right screws behind the movable mirror to make the beam spots coincident. Now the two mirrors are near parallel. (**Warning**: **Avoid FP mirror contact or collision at all times**).
6) Place a beam expander and a ground glass screen into the light path to create an area light source, so that the observer can observe a series of multi-beam interference rings as shown schematically in Figure 13.

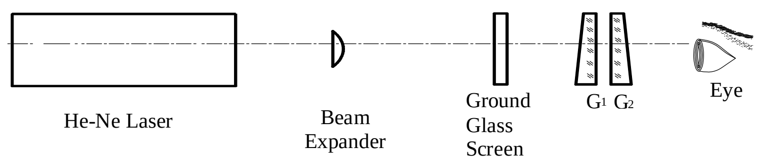


Figure 13 Diagram of the Fabry-Perot interferometer mode

If $\mathbf{G_1}$ and $\mathbf{G_2}$ are absolutely parallel to each other, the interference fringes on the ground glass screen will have a perfect circle shape (the ground glass screen should be mounted in the extension arm, see dotted lines in the structural figure shown in Fig. 4).

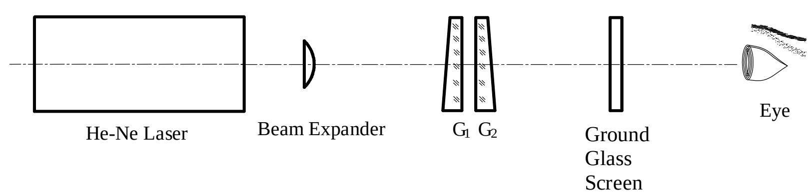


Figure 14 Diagram of the Fabry-Perot interferometer mode with ground glass screen mounted in extension arm

5.2.2 Measurement of the Wavelength of a He-Ne Laser

The interference fringes of F-P interferometer are clearer and thinner than those of Michelson interferometer. As a result, by using the same *fringe-counting* method with an F-P interferometer, the wavelength of a He-Ne laser can be measured more accurately.

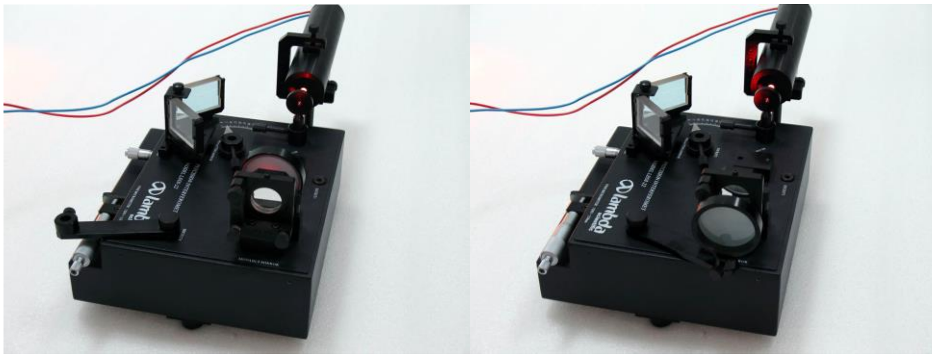


Figure 15 Fabry-Perot interferometer mode

1) Setup the F-P interferometer.
2) Adjust the interferometer carefully to produce clear circular fringes in the center of ground glass screen.
3) Record the reading d_0 of the fine micrometer.
4) Count the number of fringes that expand (or collapse) in the center of the ground glass screen as the micrometer is turned slowly (using the provided hand tally counter). After counting 50 fringes, record the micrometer reading again
6) Calculate Δd. The actual mirror movement Δd is given by

$$\Delta d = \frac{\Delta N \lambda}{2}$$

Here λ is the wavelength of the source, ΔN is the number of fringes counted, and ΔN equals 50. On the other hand, the wavelength of the light source can be determined as

$$\lambda = \frac{2\Delta d}{\Delta N}$$

7) To minimize any errors in counting the rings or recording the micrometer reading, steps 1- 6 should be repeated at least 3 times.

5.2.3 Observation of the Interference of the Sodium D-lines

If a low-pressure Sodium lamp is used as the light source in an F-P interferometer, two different sets of concentric interference fringes can be observed on the ground glass screen, as produced by the light emitted from a Sodium lamp with two different wavelengths. By turning the fine micrometer continuously, the two sets of interference fringes coincide at certain micrometer settings and separate at other settings.

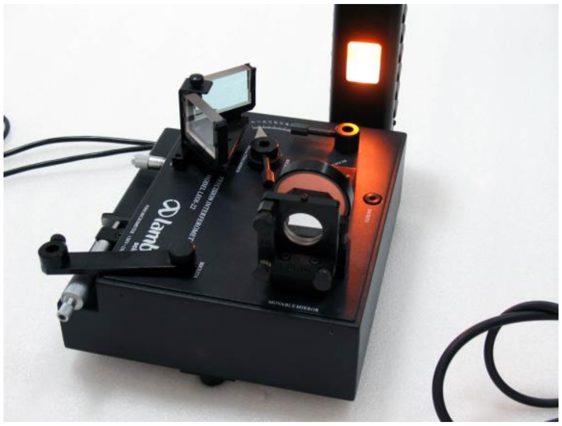


Figure 16 Fabry-Perot interferometer with Sodium lamp as light source

1) Setup the instrument in F-P mode. Use the Sodium lamp as the light source and turn it on.
2) Slowly move the movable mirror by adjusting the fine micrometer till the two mirrors are very close to each other. (The distance between them should be about 1-2 mm. Do not let them touch each other).
3) Place a pinhole plate in front of the lamp. Generally, the light beam passing through a hole in front the lamp forms a series of light spots due to the reflections of the two mirrors or they may look like a comet's tail. Adjust the movable mirror to make those spots coincide.
4) Remove the pinhole plate and adjust the movable mirror carefully till clear interference fringes are observed. For the convenience of observation, the ground glass screen should be used in the mounting hole in front of F-P mirror (Fixed Mirror).
5) Slowly turn the fine micrometer to observe the Separating- Coinciding- Separating phenomenon of the interference fringes.

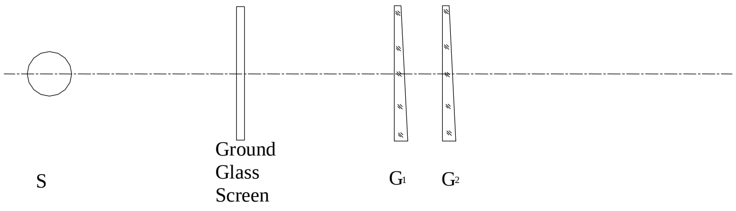


Figure 17 Diagram of the Fabry-Perot interferometer mode with Sodium lamp as light source

Note: Be careful when adjusting the fine micrometer of the movable mirror. Avoid the collision of the two mirrors.

5.3 Twyman-Green Interferometer

5.3.1 Demonstrating the Principle of a Twyman-Green Interferometer

Twyman-Green interferometer is used to check optics by parallel light. Following figures are the common configurations of a Twyman-Green interferometer in checking modes.

a) <u>Check flat mirror</u>

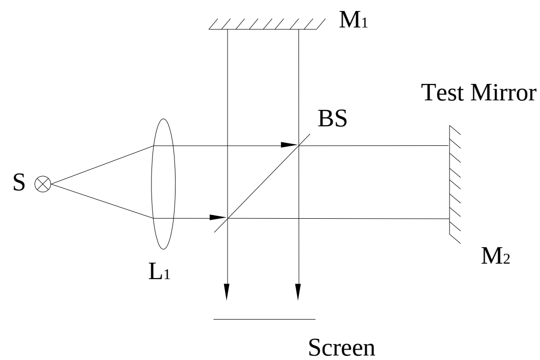


Figure 18 Configuration of Twyman-Green interferometer for checking flat mirror

Figure 18 shows the configuration diagram of a Twyman-Green interferometer for checking a flat mirror. If the mirror under test has any defects, the corresponding fringes can be observed on the screen.

b) <u>Check transparent flat optic</u>

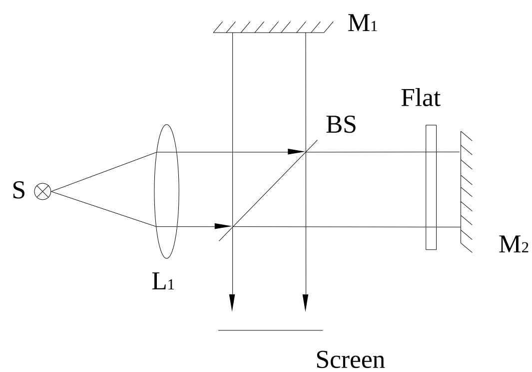


Figure 19 Configuration of Twyman-Green interferometer for checking transparent flat optic

Figure 19 shows the configuration diagram of a Twyman-Green interferometer for checking a transparent flat optic. If the flat optic under test has any defects, the corresponding fringes can be observed on the screen.

c) Check prism

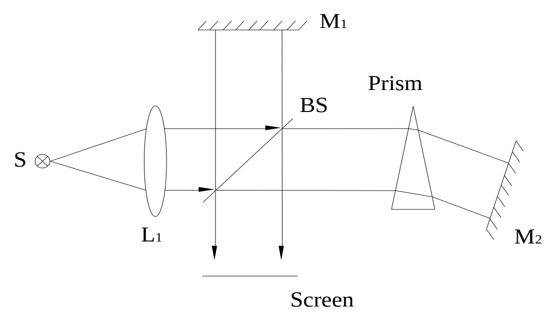


Figure 20 Configuration of Twyman-Green interferometer for checking prism

Figure 20 shows the configuration diagram of a Twyman-Green interferometer for checking a prism. If the prism under test has any defects, the corresponding fringes can be observed on the screen.

d) Check lens

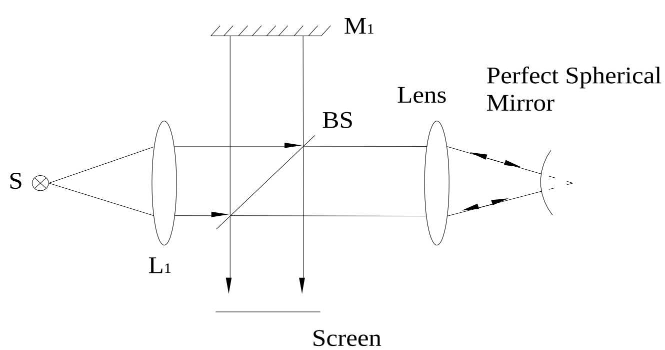


Figure 21 Configuration of Twyman-Green interferometer for checking lens

Figure 21 shows the configuration diagram of a Twyman-Green interferometer for checking a lens. If the lens under test has any defects, the corresponding fringes can be observed on the screen.

Notice:
This instrument is designed to demonstrate the principle of a Twyman-Green interferometer ONLY and it is NOT designed for practical test of optics. Here we use mode b) with the help of an expanded light source (laser and beam expander) to demonstrate the principle.

Figure 22 Twyman-Green interferometer configured for checking transparent flat optic

1) Set up the instrument according to the Michelson interferometer. He-Ne laser is used as the light source.
2) Adjust the movable mirror to get equal-thickness fringes on the screen. Refer to the particular procedures described in experiment 5.1.3.
3) Place the thin film (Sample 1 and sample 2 in turn) into the clamp and set them in SOCKET3.
4) Observe the interference fringes on the screen. If the sample has perfectly flat surfaces the fringes are perfect too. Otherwise the fringes will have the corresponding deformation and tortuosity.

6. CMOS Camera Option

6.1 Introduction to LLD-1 VGA Video Camera

Features:

- 1.3 megapixel; resolution: 1280 × 1024; clarity: > 650 TV lines
- Up to 8 movable crosshairs
- Length measurement in both H & V directions
- Sub-micron measurement accuracy
- VGA output format for PC monitor, projector or digital TV
- Easy-to-use with keypad

Specifications:

Sensor:	1.3 megapixel, color, ¼" CMOS
Resolution:	1280 (H) × 1024 (V)

Pixel size:	2.8 μm × 2.8 μm
Data:	8-bit
Frame rate:	15 frames/second (progressive scan with electronic shutter)
Clarity:	> 650 TV lines
Dynamic range:	> 63 dB
S/N:	44 dB
Sensitivity:	1 V/lux-sec (at 550 nm)
Exposure:	10 μs ~ 60 ms, auto
White balance:	auto
Lens mount:	CS/C
Output format:	VGA
Menu function:	brightness, contrast, sharpness, saturation, blue & red offset, auto exposure, H-mirror, V-mirror, negative, crosshair number & color, length calibration
Power supply:	5 VDC ± 10%, 400 mA

Installation:

- Connect the VGA OUT terminal to a VGA display using a VGA cable
- Plug the 5 V DC source of AC adaptor into the 5 V DC IN socket. The indicator becomes green. Camera is ready to use.

  Warning: <u>5 V DC only; voltage higher than 5.5 V could damage the camera; when voltage >6 V, the indicator blinks.</u>

Menu Operations with Keypad:

- Press MENU once, main menu pops up, including Picture, Setup, About, and Exit; press MENU again, main menu closes.
- Press ↑/↓to select menu, then press → to access selected menu; if there is secondary menu, press ↑/↓ to select secondary menu, then press ←/→ to change value of the selected menu.
- Select Exit menu to return to main menu.

(1) Picture

On Picture menu, picture parameters such as brightness, contrast, sharpness, saturation, and blue/red offsets can be adjusted if necessary.

(2) Setup

On Setup menu, Language (English/Chinese), Display resolution, Auto exposure, H/V mirror, number and color of hair cross, lengths dx and dy of calibration can be checked or adjusted if necessary.

(3) Screen freeze

Press POWER for one second, screen will freeze; press POWER for one second again to release freeze function.

(4) Power off

Press POWER for about 3 seconds to turn off the power of the camera.

Camera Calibration with Keypad (Optional):

- Press MENU on the keypad to show the main menu on the screen. Select “Setup”, then “Calibrate dx”, and set the length dx for the length to be used for calibration in x-direction (press ←/→ to change the value of dx).
  (1) Press CAL about 3 seconds, message pops up on the screen: Calibration dx, length =**mm.
  (2) Press SEL to highlight the line to be moved (press SEL once by once to change highlighted line). Press ←/→ to move the line to the desired scale on the ruler.
  (3) Do the same for the other line.
  (4) When the distance between the two lines equals to the set distance (i.e. =**mm), press CAL about 3 seconds, message pops up on the screen: calibration dx: OK, dx=**mm. Calibration for x-direction is successful.
- Similarly, do calibration for y-direction with the procedure described above.
- After camera calibration, use keys SEL, ↑, ↓, ← and → to move lines to measure distance between a pair of horizontal or vertical lines.

6.2 Mounting of Video Camera

In the absence of camera, adjust the interferometer to achieve expected interference pattern on the ground screen.

Insert the camera lens into the camera lens holder (ϕ30 mm) and fix it. Mount the post of the lens holder to the mounting hole (ϕ12.7 mm) of holder SZ-09. Mount the assembly of SZ-09 with camera to the lower portion of the post of the ground glass screen (ϕ10 mm) through the other hole of SZ-09, where the ground glass screen is already mounted on the Extension arm, as shown in Figure 23. Adjust camera height and lens focus to achieve clear interference pattern on the VGA display, as shown in Figure 24. **Note**: fringe image cannot be acquired properly by the camera alone without the use of the ground glass screen.

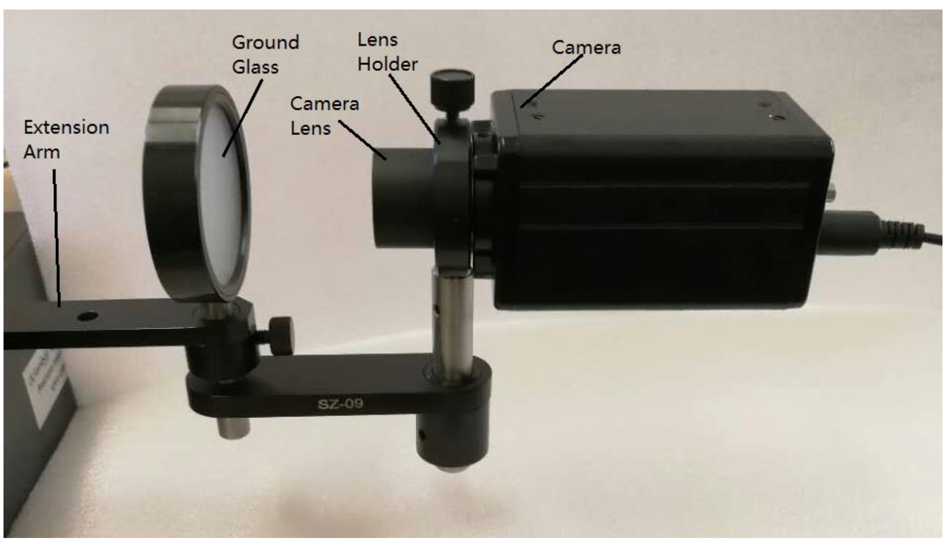


Figure 23 Photo of ground glass screen and camera assembly

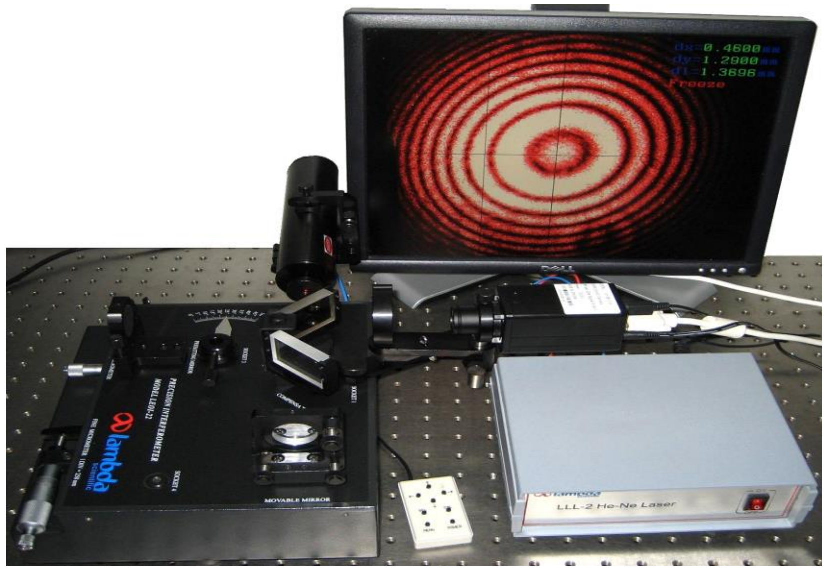


Figure 24 Fringe image displayed on PC monitor from camera

7. Maintenance

7.1 Optical Components

Please do not wipe the surfaces of optical components. If necessary, remove the surface dust with a clean soft brush, or use an absorbing cotton tip dipped by the mixture of ethanol and aether. The surface of optical components should never be touched by bare hands.

7.2 Driving Mechanism

Careful adjustment required. Do not push the coarse micrometer and fine micrometer by force. Please do not disassemble the driving mechanism as otherwise permanent damage to the driving mechanism may occur.

8. Laser Safety and Lab Requirements

Follow the corresponding laser safety guidelines based on AS/NZS 2211.1:1997 and other lab instructions about optical components etc.

The output power of the He-Ne laser is less than 1 mW at 632.8 nm (class IIIa), so **<u>direct eye exposure to the laser beam should be avoided.</u>**

9. Handling Precautions and Safety Warning of Low-Pressure Sodium Lamp

<u>Operation and Handling Precautions:</u>

- Do not touch the glass cover of the Sodium lamp with bare hands, wear plastic gloves when handling the lamp to avoid finger prints or oil grease on the glass cover.
- Make sure the electric power to the lamp is turned off when installing or removing the lamp to or from the housing.

- The lamp is designed to work with the housing provided in upright orientation. Using the lamp with other housings or in other orientations is prohibited.
- The Sodium lamp needs a warm-up time of approximately 20 minutes to reach steady output.
- Once the lamp is turned on, the housing can become very hot over time so avoid touching the hot housing or moving it around.
- After turning the lamp off, wait at least 30 minutes for the lamp to cool down before turning the lamp back on or moving the housing around.
- The lifetime of the lamp decreases with an increase in the number of turn-on/turn-off times of the lamp.
- The low-pressure Sodium light source is NOT designed for personal or consumer use at home.

Safety Warning:

- Sodium contained in the light bulb, constitutes an ignitable hazardous waste when reacted with water under the case of a broken lamp.
- In the case of glass cuts by a broken lamp, do not use water to clean cut. Use antiseptic cream instead and seek medical treatments immediately.
- Prior to lamp disposal, the lamp has to be broken into pieces in a dry container with strict safety and handling precautions. The operator must wear gloves and safety goggles to prevent the possibility of injury from broken glasses. The operation should be conducted in a well-ventilated area to avoid inhalation of the dust when breaking up the lamp. The broken lamp should be covered with water from a water hose, with the operator standing from a safe distance (5 meters away from the broken lamp). After a few minutes when the reaction between Sodium and water is complete, the broken lamp can be disposed as broken glasses.*

*Subject to applicable federal, state, and local regulations.