Michelson Interferometry

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Michelson Morley's interferometer together with Einstein's theory of relativity helped in abandoning the concept of ether in the classical experiment performed in 1887. Since then, interferometers are used for many purposes, e.g., one of the most exciting and grand goals is measuring gravitational waves. The Laser Interferometer Gravitational-wave Observatory (LIGO), is a collaborative project of American universities aimed at detecting waves of gravitational origin.
The goal of the current experiment is to familiarize students with the Michelson Interferometer. It introduces optical components like beam splitters, translation and rotational stages, lenses and highlights important concepts in wave interference. Michelson interferometer is used for measuring the laser wavelength and finding the refractive index of glass.

KEYWORDS

Interferometer · Beam Splitters · Optical alignment · refractive index · constructive and destructive interference · optical path length ·

APPROXIMATE PERFORMANCE TIME 1 week.

1 List of Equipment

1. HeNe Laser with Mount, HR020, Thor Labs

2. Economy Beam Splitter, EBS1, Thor Labs

3. Protected Silver Mirror ME1-P01, Thor Labs

4. Post Holders PH3/M, PH3-ST, Thor Labs

5. Stainless Steel Posts, TR150/M, Thor Labs

6. Laser Mounting and Clamp C1501/M, Thor Labs

7. Laser Clamping Arm, PM2, Thor Labs

8. Cage Mount for lens, CP02, Thor Labs

9. Lens Mount, LMR1/M, Thor Labs

10. Kinematic Mirror Mounts KM100-E02, Thor Labs

11. Plano-Convex lens f=25.4mm, LA1027, Thor Labs

12. Plano-Convex lens f=35mm, LA1951, Thor Labs

13. Precision rotation platform, PR01/M, Thor Labs

14. DC Servo Motor Controller, Z825B, Thor Labs.

2   Experimental Objectives

The experimental objectives include:

1. working with optical components,

2. optical alignment of the interferometer,

3. Understanding the concept of change in optical path length,

4. measuring the wavelength of the HeNe laser, and

5. finding refractive index of thin glass sheet.

References and Essential Readings

[1] Ryan Scholl and Bruce W. Liby, "Using a Michelson Interferometer to Measure Coefficient of Thermal Expansion of Copper", The Phys. Teach. **47**, 316-318 (2009).

[2] Eugene Hecht, "Optics", Chapter 9, pg 407-412, Pearson Education, 2002.

[3] Monk, "Light: Principles and Measurements", pg 376-380, McGraw-Hill, 1937.

[4] Al-Azzawi, "Physical Optics, Principles and Practices", Chapter 4, CRC press, 2007.

[5] "The index of refraction of glass", Precision Interferometer, PASCO Scientific.

[6] "The Michelson Interferometer", University of Central Oklahoma, 2003.

[7] Jeremy Ong, "Investigations of Light with a Michelson Interferometer", Cornell University, 2010.

[8] J.J. Fendley, "Measurement of refractive index using a Michelson interferometer", Phys. Educ. **17**, 209-211 (1982).

3   Introduction

An interferometer exploits the interference of light, a wave property. A fringe pattern results from optical path differences. The Michelson Interferometer is an amplitude-splitting interferometer. Figure 1 shows the schematic whereas Figure 2 is a photograph of a typical setup you will have to build in the lab. The working of the interferometer is described in detail [2, 4] and you are required to carefully read the background material.

4   Optical alignment of the Michelson interferometer

Q 1.   Perform the following procedure to align the interferometer.

1. Place the HeNe laser into laser mount which is bolted on the optical breadboard. Align the laser parallel to the breadboard.

2. Now mount the beam splitter (BS) on the breadboard in front of laser.

3. Place a fixed mirror (M1) in the mirror mount assembly. Align the mirror such that the reflected beam from BS falls in the middle of it.
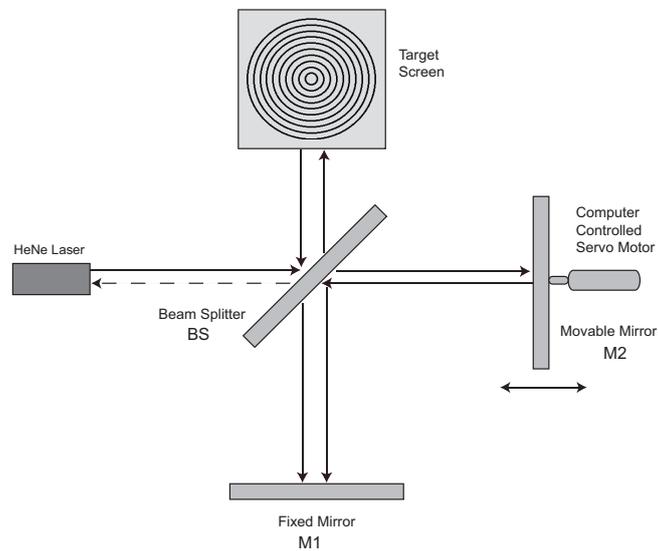
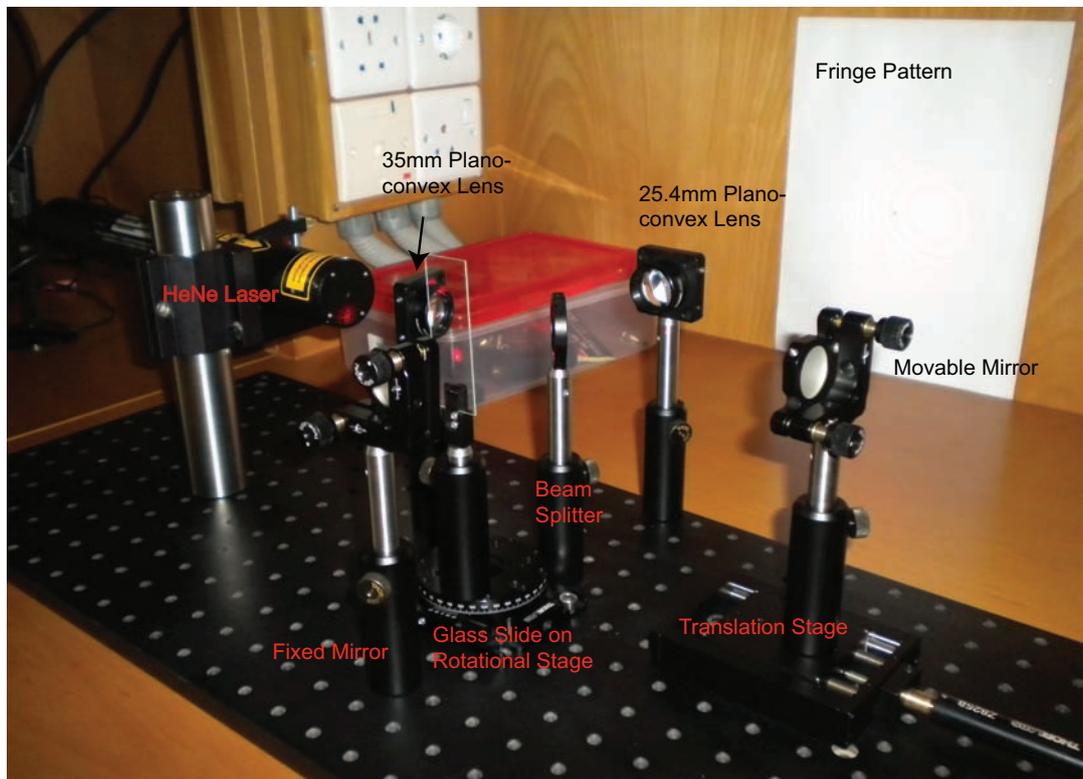Figure 1: Working of the Michelson Interferometer.

Figure 2: Laboratory setup of Michelson Interferometer.

4. Now mount the other mirror (M2) on the translation stage which is being operated by the computer controlled servo motor. Align M2 such that the transmitted beam from BS falls in middle of it.

5. Turn ON the laser, you shall see the three small dot images. Using the screws of the mirrors, overlap all three dots. Now the two beams will be aligned.

6. Place the plano-convex lens of focal length 35 mm (L1) in between laser and BS.

7. On the opposite side of M1 place another plano-convex lens of focal length 25.4 mm before the target screen to enlarge the image.

8. Carefully adjust M1 and M2 using their screws so that the beams overlap on the target.

9. Perform alignment until you see concentric circular fringes.

5 Measuring wavelength of the laser using Michelson Interferometer

If we move the movable mirror we see the fringes entering or exiting the center of the fringe pattern, depending upon the direction in which the mirror moves. The following equation relates the the distance moved by the mirror with the number of fringes passed by.

$$\lambda = \frac{2\Delta d}{N} \tag{1}$$

where, λ is the laser wavelength, N is number of fringes passed by and Δd is the distance moved by M2. You must understand the derivation of Equation (1).

Q 2. Perform the following procedure to measure the wavelength of the HeNe laser.

1. Use the computer software to move M2 using the servo controlled motor by a fixed distance of around 10 um. The software Instructions and Servo motor specifications are given in Appendix A.

2. Count the number of fringes that passes by a fixed point.

3. Fringes shall be entering on exiting center depending on the direction in which you move M2.

4. Repeat the same procedure at least 5 times and takes the average to minimize the errors.

5. Use equation (1) to measure the laser wavelength. What is your uncertainty in the wavelength?

6 Measuring refractive index of glass

Glass slide is mounted on the rotational stage and placed in between BS and M1. If we rotate the glass slide we see the fringes entering or exiting the center of the fringe pattern, depending upon the direction in which the rotation takes place. The refractive index is,

$$n_g = \frac{(2t - N\lambda)(1 - cos\theta)}{2t(1 - cos\theta) - N\lambda} \tag{2}$$

where, n_g is the refractive index of glass, λ is the laser wavelength, t is the thickness of glass slide, N is number of fringes passed by and θ is the angle rotated in radians.

Q 3. Draw a figure showing the path of the light beam as it passes through the glass slide at an arbitrary angle θ with respect to the light ray. What is the optical path length difference in this case?

Q 4. Derive Equation (2).

Q 5. Plot N versus θ as elicit by Equation (2).

Q 6. Perform the following procedure to find the refractive index of glass slide.

1. Find the thickness of the glass slide.

2. Place the glass slide on the rotational stage in between M1 and BS such that it is exactly parallel to M1.

3. Rotate the glass slide by certain number of degrees and count the number of fringes that passes by a fixed point.

4. Fringes shall be entering on exiting center depending on the direction in which you rotate the glass slide.

5. Use equation (2) to compute the refractive index of glass.

6. Repeat the same procedure at least 5 times and take the average result to minimize the error. Remember that the relationship (2) between N and θ is nonlinear.

7. Calculate the uncertainty in n_g arising from the uncertainties in N and θ.

Q 7. Does your experimental results verify the relationship?

7 Appendix A

7.1 Software Instructions

1. Open "APT Configuration Utility", and select the following Motor and Stage options. Motor 83823465, Channel 1 and Stage $Z825$.

2. After configuration, run "APT User Utility".

3. Select the "Motor driver Settings" tab and enter the following parameters,

    (a) In Moves-Velocity Profile,
       Max. Vel. = 0.0003 mm/sec,
       Acc./Dev. = 0.03 mm/sec/sec,

    (b) Step distance = 0.001 mm.

4. After completing the settings, right click on the panel window and select "Graph view". On right side of the screen you can see the Channel position (current position) and cursor position (desired position). Adjust the cursor position such that the difference in between both positions is around Δd.

5. Click the moves and stop button to operate the servo motor.

7.2 DC Servo Motor Specifications

Travel range = 25 mm
Lead Screw Pitch = 1 mm
Resolution = 29 nm