Exp. No. 5

OPTICS LAB

Mach Zehnder Interferometer

The Mach Zehnder interferometer is a particularly simple device for demonstrating interference by the division of amplitude. A light beam is split into two parts by a beam splitter and is then recombined after they traverse along different paths. Depending on the relative phase acquired by the beam along the two paths fringe patterns are obtained. The Mach Zehnder interferometer has found many applications. Starting as interferometer of choice for visualizing flow in wind tunnels during the early days of aerodynamics they are also used as electro optic modulators. They are also now being employed to study quantum entanglement. This manual will help you understand the basic aspects of this interferometer.

Objective:

Assembling a Mach Zehnder interferometer to observe the interference pattern. Determine the refractive index of air as function of pressure.

Components and Equipment:

- Laser Optics Base Plate
- Diode Laser with laser mount
- 2 Beam Splitters with mounts
- 2 plane mirrors mounted on translational stage
- Pressure Cell
- Screen

1 | Theory

Optical interference corresponds to the interaction of two or more light waves yielding a resultant irradiance that deviates from the sum of the component irradiances. It can be achieved in broadly two different ways: wave-front splitting (e.g.: Young's double-slit experiment which you learned during your high school days) and amplitude splitting (e.g.: Michaelson Interferometer, Mach Zehnder Interferometer, Watch Quantum Mechanics lecture by Barton Zweibach, MIT). In today's lab, you will learn how to set up and learn about the most popular way of obtaining circular fringe patterns using amplitude splitting.

The Mach Zehnder interferometer uses a coherent light beam from a suitable source which is split into two parts using an optical component such as a beam splitter. These partial beams travel along two different paths until they are deflected using mirrors and channeled to a detector behind another beam-splitter where they combine and superimpose. If the coherence between the two partial beams is not destroyed it will result in interference forming circular fringes on the screen.

2 | Setup

Note: Optical components with damaged or dirty surfaces can cause disturbances in the interference pattern. So, handle the planar mirrors and beam dividers carefully.

The components must be aligned particularly carefully with regard to the geometry of the beam path. To set up the experiment correctly, you must carry out the following steps:

Laser optics base plate and laser

- Mount the laser on the laser support and place it at a suitable edge of the base plate
- Connect the laser and switch it on
- Remove the beam expander in front of the laser. It helps a lot.
- Loosen the lock nuts and adjust the height, the inclination of the laser so that the laser beam travels perfectly horizontally.
- Don't forget to tighten the lock nuts

Refer to the schematic below for the configuration and alignment of the set up.

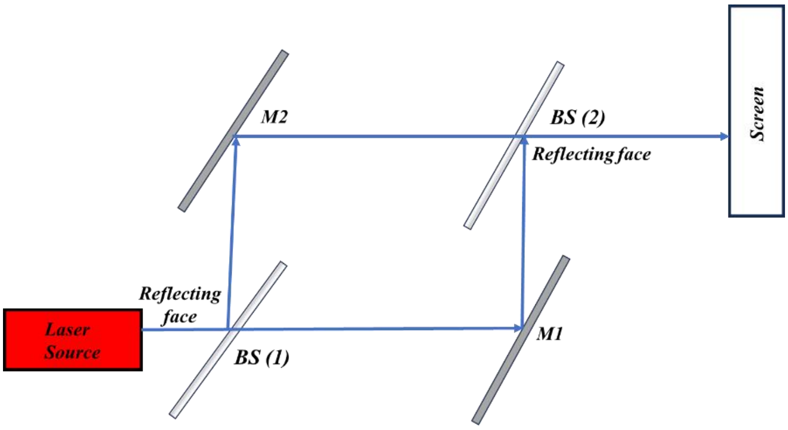

Fig:1 Schematic of the Experimental Set Up

Preliminary adjustments

- Now place one of the beam dividers (BS 1) with optic base in the beam path at 45^0 so that the incident light is split along two mutually orthogonal directions. Note that in addition to the main beam there might be *parasitic partial beams* of low intensity. The reflecting surface of BS 1 should be facing the laser beam. The configuration ensures that the two beams reaching the screen or detector interfere in phase.
- Once the above step is done place the plane mirrors at M_2 and M_1 inclined at 45^0 in the path of the reflected and transmitted beam respectively ensuring that the beam deflects at an angle of another 45^o to the second beam splitter (BS 2).
- Put a screen beyond BS 2 at a far enough distance. You will see two bright spots on both the two screens. If not, you have messed up. Correct it!

Subsequent adjustments

- Ensure the beams are close to the center of the optical components.
- Shift the mirrors and beam splitters horizontally or vertically to ensure that the two spots on the screen coincide.
- Once done, check whether the paths traced by the partial beams from the beam divider trace out the Latin letter L. YOU MUST ENSURE THE PATH TRAVERSED IS OF EQUAL LENGTH.

Fine adjustments

- Now add in the beam diffuser in front of the laser.
- Change the beam path by slightly changing the alignment of the beam dividers or the plane mirrors
- If the interference pattern pops up congratulations you completed the first two objectives. Readjust slightly to ensure that the fringes form close to the center of the screen.

If you have done everything perfectly, you will see concentric fringes like this:

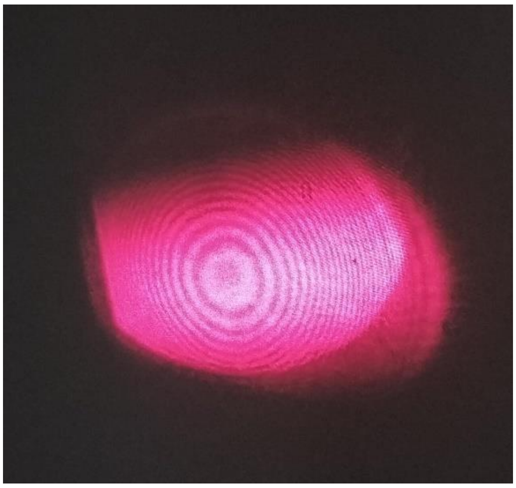

Fig: 2 Concentric Circular fringes before placing the pressure cell

Take a clear photograph of the concentric fringes using your smartphone and attach it while submitting the record next week. Also, the observations section that you will scribble in the record, get it signed by your teaching assistant. Only then move to the next section

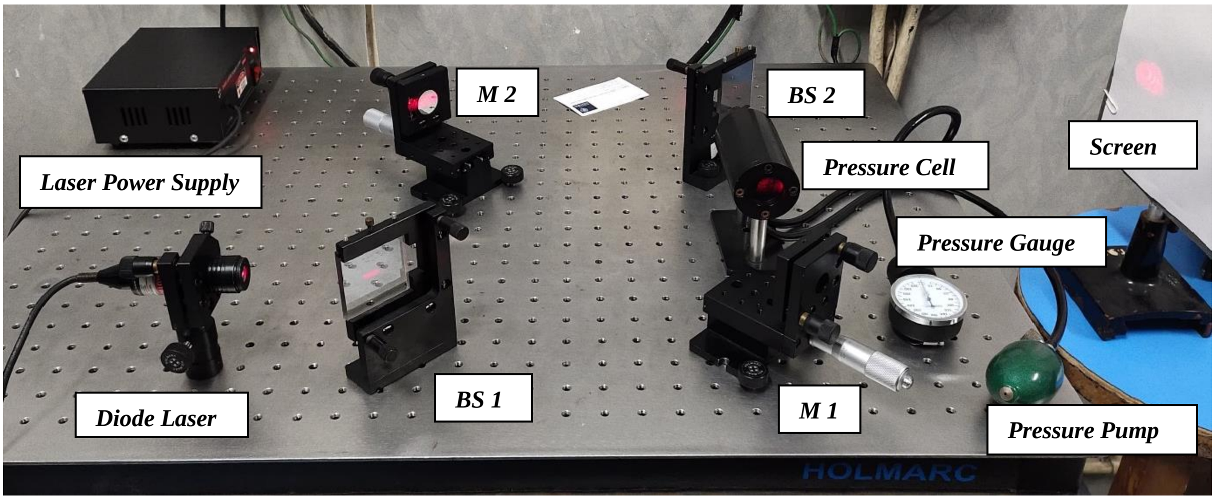

Fig:3 Experimental Set Up

3 | Variation of Refractive index of air with pressure

Don't just get carried away when you finish section 2 because this is the main part of the experiment. Before going through the steps let me first state the requisite theory. By changing the pressure along one of the arms, you are necessarily changing the density (recall Gas Laws. What kind of relationship do they have?) in turn changing the refractive index to some 'n'. So, if the optical path is initially of length nL then by introducing the pressure cell you have essentially changed the *effective* path length of one of the beams. As a result, you will see shift of m-fringes due to a change in the refractive index by an amount

$$\Delta n = m\lambda / L$$

The refractive index for most gases is close to 1. For air and other ideal gases, the difference between the refractive index is proportional to the pressure of the gas. Thus, I will define the refractive index of air as:

$$n = 1 + kp \tag{1}$$

where p is the air pressure and k is an unknown constant. So, when the pressure is changed, it affects the refractive index as $\Delta n = k \ \Delta p$. We can, therefore, relate the number of fringes shifted, m, to change in pressure $\Delta p = \Delta n/k = m\ \lambda/(Lk)$.
The above equation can be re written as:

$$P_{final} = -\frac{m\lambda}{Lk} + P_{initial}$$

Thus, plotting the graph between the Pressure and the corresponding fringe shift can help in determining the constant 'k' given by

$$k = \frac{-\lambda}{L(slope)}$$

Where L is the path travelled by the laser beam
inside the pressure cell

1. L = 9 cm (measure it to be sure)
2. Wavelength of laser (as mentioned in the laser source)
3. P_{atm} = 760 mm of Hg

Follow the steps below to take the readings

- Place the pressure cell in one of the arms of the interferometer. The pressure inside the cell can be changed using the squeezable bulb and pressure control valve. (Ensure that it is working and the pressure drops gradually!)
- Don't lose the fringes while doing so. Now pump the rubber bulb and increase the pressure to its maximum possible value and quickly tighten the pressure control valve.
- Release the pressure gradually and count the number of fringes moved. Tabulate the number

of fringe shift against air pressure.

- Plot a graph between number of fringes vs the corresponding pressure. Then find k and get refractive index of air by using equation (1).

Tabulate them as follows:

Sl. No	Pressure measured (units)	Number of fringes shifted

Take at least five readings and again individually. So, in total as a group, you must have fifteen readings. Get at least three among that fifteen signed by your TA.

Error Analysis:

We have,

$$k = \frac{-\lambda}{L(slope)}$$

Differentiating above,

$$\Delta k = \frac{\lambda(\Delta\ slope)}{L(slope)^2}$$

which gives,

$$\Delta n = \frac{\lambda}{L}\frac{(\Delta\ slope)}{(slope)^2}P$$