PSE605A (Photonics Lab Techniques)

Lab Report: Experiment 5

MACH-ZEHNDER

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Mach-Zehnder Interferometry

1 Objective

Interferogram of a heated plate using Mach-Zehnder interferometer.

2 Apparatus

He-Ne Laser, Beam-splitters with mount (2 nos.), Mirrors with mounts (2 nos.), Photo-detector, Heated Plate.

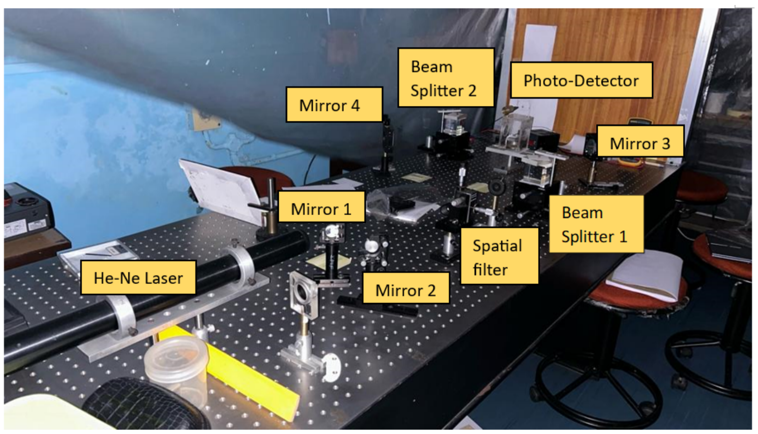

Figure 1: Set up

3 Theory

This experiment aims to measure the refractive index of air using the Zehnder interferometer method. The temperature is measured using a test cell placed in one of the optical arms of the Mach-laser beam. The beam is cleaned and collimated using a spatial filter and collimating lens. Both arms have the same path length. To conduct the experiment, a heating element is placed in the test arm of the beam and covered with a perspex cell to maintain the temperature of the air inside and avoid any external disturbances. The change in optical path length is

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

Where, is the refractive index, L is physical path length and m is an integer. We define the refractive index of air as

$$n = 1 + \Delta n$$

Where $\Delta n = k * \Delta T$.
Where k is the proportionality constant and ΔT is the change in temperature.
So, we can write,

$$k = \left(\frac{\Delta m \lambda}{\Delta T L}\right)$$

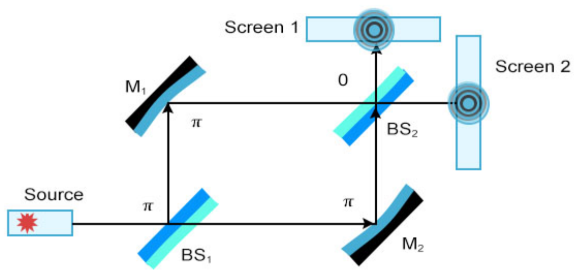

Figure 2: Shematic diagram of Mach-Zehnder Interferometer

4 Procedure

The procedure is given below:
1. Align the laser beam with the top of the base so that it strikes the centers of the mirrors.
2. Adjust the objective lens using the pinhole in the path of the laser to ensure that the maximum amount of light passes through it without deviating from its original path.
3. Adjust the angle of the beam splitter BS1 so that the reflected beam hits the fixed mirror M1 near its center. Then, adjust the mirror M1 so that the reflected beam hits BS2 at its center.
4. You should now see two sets of bright patches on the screen, one coming from mirror M1 and the other from mirror M2. Adjust the angle of the beam splitter BS2 and the mirror M2 so that the two sets of patches overlap on BS2 and the beams run parallel to each other as they move away from BS2. You can check this by moving the screen on the base plate.
5. Adjust the second arm beam so that it goes slightly above and touches a small part of the temperature cell. This ensures a significant path difference due to temperature.
6. Observe the maximum and minimum values of fringes with the photodetector. If the difference is less, adjust the spatial filter again to achieve significant contrast. Then, set the photodetector pinhole at the maximum of the fringe pattern.
7. It may require some skillful observation and adjustment to get the fringes. Please note that this written procedure is only a guideline.

5 Graph

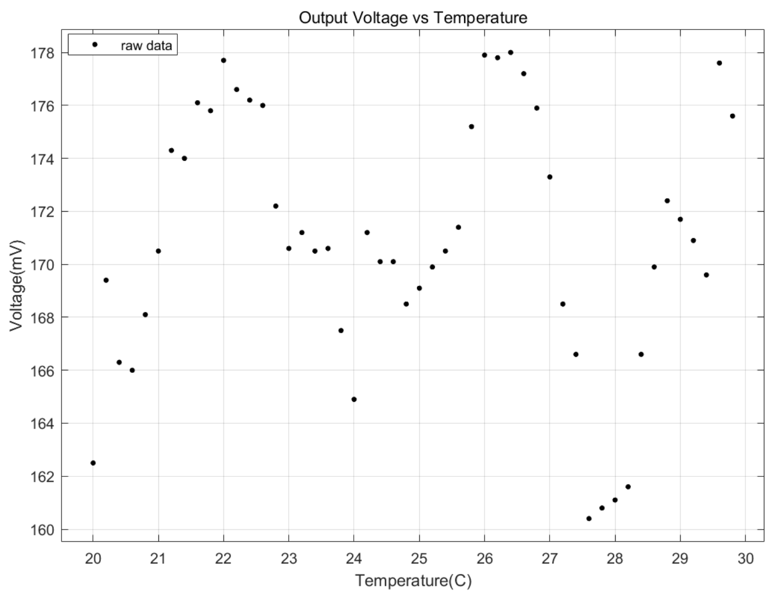

Figure 3: Voltage vs Temperature curve (raw data)

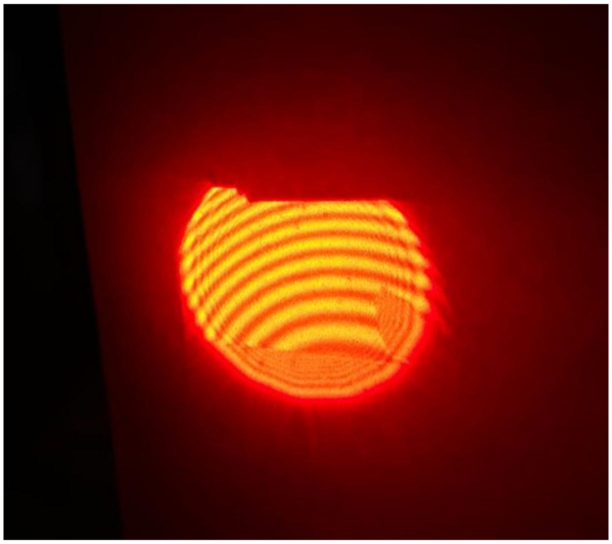

Figure 4: Fringe at room temperature

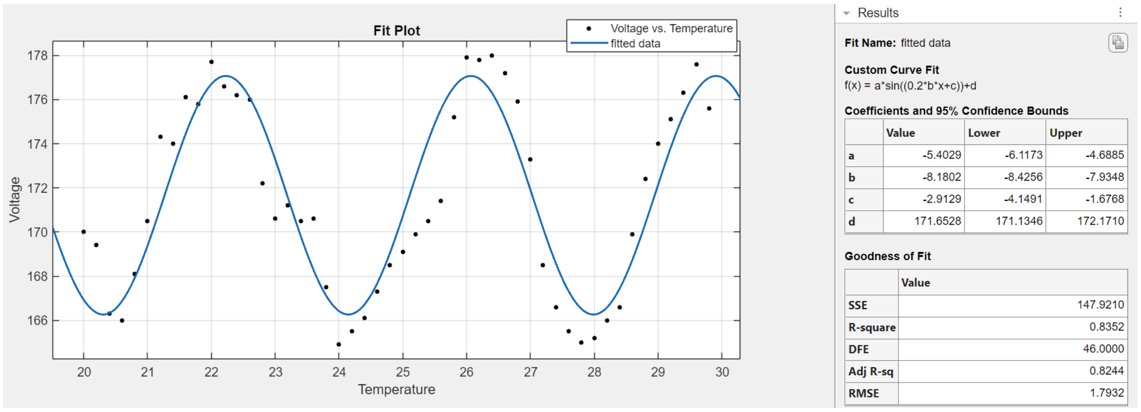

Figure 5: Voltage vs Temperature fitted curve

Note:
The fitted equation is

$$\boldsymbol{a * sin((0.2 * bx + c)) + d}$$

Where,

$$a = -5.4029$$

$$b = -8.1802$$

$$c = -2.9129$$

$$d = 171.6528$$

$$\boldsymbol{AdjR - sq = 0.8244}$$

6 Calculations

6.1 Refractive Index

From the fitted plot, the maximum output voltage is 177.05 mV at 22.20 $°C$ and 26.08 $°C$.
So,

$$\Delta T = 26.08 - 22.20 = 3.88\ °C$$

we know, λ=632.8 nm, L=0.0342 m, $\Delta m = 1$.
Given formula,

$$k = \left(\frac{\Delta m \lambda}{\Delta T L}\right)$$

$$= \left(\frac{1 * 632.8 * 10^{-9}}{3.88 * 0.0342}\right)$$

$$k = 4.77 * 10^{-6}$$

So,

$$\Delta n = k * \Delta T$$

$$= 3.88 * 4.77 * 10^{-6}$$

$$\mathbf{\Delta n = 1.85 * 10^{-5} = 0.0000185}$$

So, the change in refractive index is 0.0000185.
So,Refractive index,

$$n = 1 + \Delta n$$

$$= 1 + 0.0000185$$

$$n = 1.0000185$$

So, the **refractive index** is **1.0000185**.

6.2 Visibility

The maximum output voltage is 177.05 mV at 22.20 $°C$.
The minimum output voltage is 166.25 mV at 24.26 $°C$.
We know,

$$|v| = \left(\frac{I_{max} - I_{min}}{I_{max} + I_{min}}\right)$$

$$= \left(\frac{177.05 - 166.25}{177.05 + 166.25}\right)$$

$$\mathbf{|v| = 0.0314}$$

7 Appendix

Table 1: Output voltage at different temperature

sl no	Temperature °C	**Voltage (mV)**
1	20.000000	162.500000
2	20.200000	169.400000
3	20.400000	166.300000
4	20.600000	166.000000
5	20.800000	168.100000
6	21.000000	170.500000
7	21.200000	174.300000
8	21.400000	174.000000
9	21.600000	176.100000

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Table 1 – continued from previous page

sl no	Temperature °C	**Voltage (mV)**
10	21.800000	175.800000
11	22.000000	177.700000
12	22.200000	176.600000
13	22.400000	176.200000
14	22.600000	176.000000
15	22.800000	172.200000
16	23.000000	170.600000
17	23.200000	171.200000
18	23.400000	170.500000
19	23.600000	170.600000
20	23.800000	167.500000
21	24.000000	164.900000
22	24.200000	171.200000
23	24.400000	170.100000
24	24.600000	170.100000
25	24.800000	168.500000
26	25.000000	169.100000
27	25.200000	169.900000
28	25.400000	170.500000
29	25.600000	171.400000
30	25.800000	175.200000
31	26.000000	177.900000
32	26.200000	177.800000
33	26.400000	178.000000
34	26.600000	177.200000
35	26.800000	175.900000
36	27.000000	173.300000
37	27.200000	168.500000
38	27.400000	166.600000
39	27.600000	160.400000
40	27.800000	160.800000
41	28.000000	161.100000
42	28.200000	161.600000
43	28.400000	166.600000
44	28.600000	169.900000
45	28.800000	172.400000
46	29.000000	171.700000
47	29.200000	170.900000
48	29.400000	169.600000
49	29.600000	177.600000
50	29.800000	175.600000

8 Observations and Discussions

- **Observe interference pattern:** Using two beam splitters, we create two different beams. In the screen, we get bright and dark fringes due the constructive and destructive interference.
- **Effect of temperature:** While we start the changing temperature, the refractive index of the air increases. That's why, the path length of that particular beam increases. So, the path difference changes. For this reason, the fringe moves with the changing of the temperature. That's why we get sinusoidal output.
- **Change in refractive index:** In our case, we saw λ path difference is created for 3.88 $^\circ C$. For this temperature changing, the change in refractive index is very low (order of 10^{-5}).
- **Visibility:** In our case, we got the visibility 0.0314. This is not a very good result. It indicates that there were some alignment problems.
- **Improvement in result:** To change the temperature, if we could use such a device which keeps the temperature at desire point, then we might get a better result.
- **Importance:** The Mach-Zehnder interferometer is an instrument that can detect changes in pressure, density, and temperature of gases by measuring the phase shifts caused by these changes. It has potential applications in aerodynamics and plasma physics.

9 Source of Error

- **Lack of alignment:** If the components are not aligned perfectly, the clear fringe will not be visible. It might be a source of error.
- **Noise:** Any noise unstabilizes the fringe. Then the output voltage will fluctuate. It adds the error.
- **Continuously changing temperature:** To get the correct output voltage at any temperature, the temperature must be fixed for a while to stabilize output. But it does not happen in our case. That's why it adds an error.
- **Lack of completely dark room:** To take the output data, the torch is used. So, the room never be completely dark. So, it adds noise to the output.

10 References

- "Optics" by Eugene Hecht 5th edition.
- K P Zetie et al, 2000, Phys. Educ. 35, 46
- https://www.gophotonics.com/community/what-is-a-mach-zehnder-interferometer