FABRY-PEROT INTERFEROMETER

Objectives:

I. Alignment of Fabry-Perot Interferometer to observe concentric circular fringes

II. Measurement of the wavelength of a diode Laser

III. Determination of difference in wavelengths of sodium doublet

Introduction

The Fabry-Perot interferometer uses the phenomenon of multiple beam interference that arises when light shines through a cavity bounded by two reflective parallel surfaces. Each time the light encounters one of the surfaces, a portion of it is transmitted out, and the remaining part is reflected back. The net effect is to break a single beam into multiple beams which interfere with each other. If the additional optical path length of the reflected beam (due to multiple reflections) is an integral multiple of the light's wavelength, then the reflected beams will interfere constructively. More is the number of reflection inside the cavity, sharper is the interference maximum. Using Fabry-Perot (FP) interferometer as a spectroscopic tool, concepts of finesse and free spectral range can be understood.

Principle of Working

The basic principle of working of the Fabry-Perot interferometer is schematically explained in the adjacent figure. Two partial mirrors **G1** and **G2** are aligned parallel to one another at a distance d, forming a reflective cavity. When irradiated by a monochromatic light (a laser here) of wavelength λ at an angle of incidence θ, multiple reflections takes place inside the cavity. Part of the

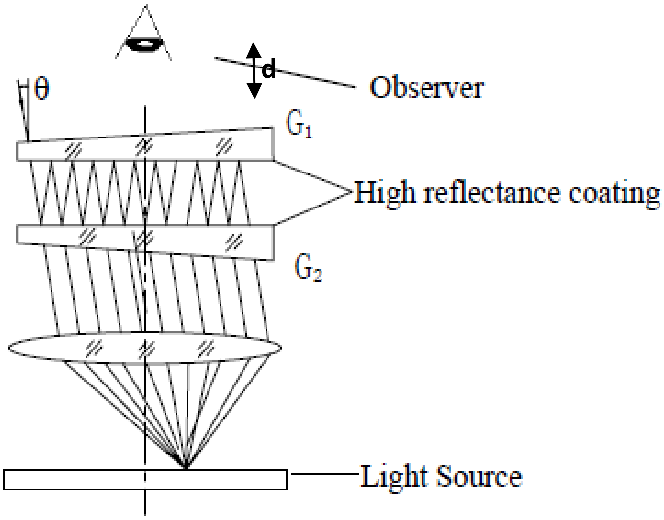

Fig. 1: Schematics of a Fabry-Perot Interferometer

light is transmitted each time the light reaches the second reflecting surface. All such transmitted light rays interfere with each other to give rise to a maxima or minima depending on the path difference between them. Let n be the refractive index of the medium in the cavity (in this case it is air). Then the optical path difference between two neighbouring rays is:

$$\Delta = 2nd\cos\theta \quad \ldots \quad \ldots \qquad (1)$$

Then the phase difference is given by $\delta = (\frac{2\pi}{\lambda})\Delta \ldots \ldots$ (2)

In the figure below calculation of path difference is shown for a general cavity is shown where α and β are the angles of incidence and refraction, respectively.

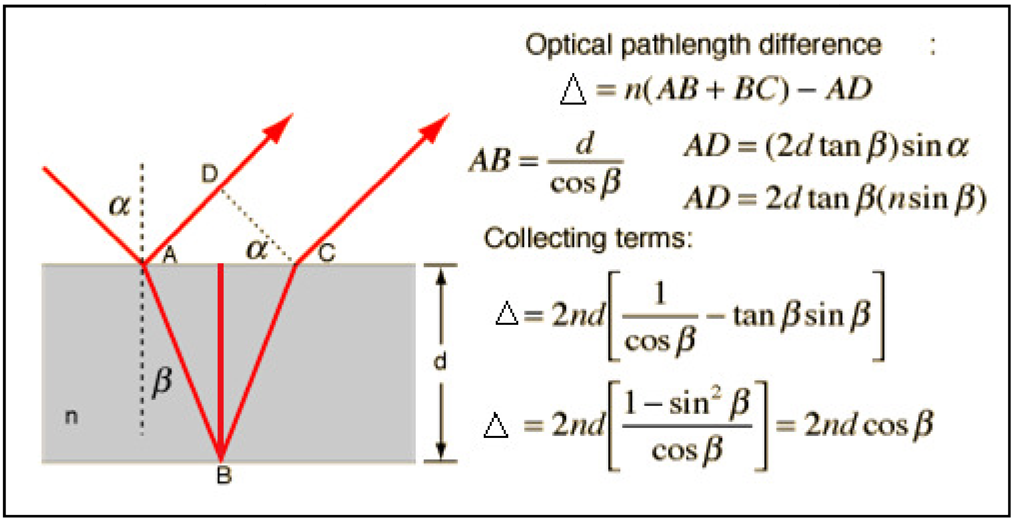

Fig 2. Calculation of path difference

Thus, the resultant transmitted light intensity I_T is:

$$I_T = I_0 \frac{1}{1+\frac{4R}{(1-R)^2}\sin^2\frac{\delta}{2}} \quad \ldots \quad \ldots \qquad (3)$$

where, I_0 is the incident intensity, R is the reflectivity of the mirrors. It can be noticed that I_T varies with δ.

I_T is maximum when $\Delta = m\lambda$ ($m = 0, 1, 2\ldots$) or $\delta = 2m\pi$ … … (4)

and minimum when $\Delta = (2m+1)\lambda/2$ ($m = 0, 1, 2\ldots$) or $\delta = (2m+1)\pi$ … (5)

The complete interference pattern appears as a set of concentric rings. The sharpness of the rings depends on a parameter called coefficient of finesse, F, defined as $F = \frac{4R}{(1-R)^2}$.

Determination of wavelength λ : Using the relations 1 and 4 (or 5) wavelength of the incident light can be determined accurately. Let the initial separation between the mirrors is d_1. If one counts the number of fringes (say maxima) appearing or disappearing at the centre ($\theta \approx 0$) by varying the distance between the mirrors to d_2, then λ can be determined as follows:

$2d_1 = m_1 \lambda$, $2d_2 = m_2 \lambda$, $m_2 - m_1$ = Number of maxima counted

$$\boldsymbol{\lambda = \frac{2(d_2 - d_1)}{m_2 - m_1}} \quad \ldots \quad \ldots \quad (6)$$

Determination of difference in wavelengths of sodium doublet (Δλ):

The Fabry-Perot interferometer can be used for measurement of the wavelength separation of sodium D-lines. The yellow sodium doublet consists of two wavelengths whose values are very close to each other, i.e. 589 and 5896 nm. Therefore, during the process of moving the interferometer's movable mirror, the interference fringes produced by the two yellow lines will appear periodically clear and blurry (due to splitting). For a given separation ($2d_1$) of the mirrors, maxima of the two wavelengths coincide to give a clear fringe pattern and satisfy the following relation:

$$2d_1 = m_1 \lambda_1 = m_2 \lambda_2 \quad \ldots \quad \ldots \quad (7)$$

where m_1 and m_2 are respective orders of maxima for λ_1 and λ_2. Due to difference in wavelength, when the mirror is moved the corresponding fringes will not move equally and the pattern will be blurry. On further movement the pattern becomes clear again where the *m*th order of the longer wavelength coincides with (*m*+1)th order of the shorter wavelength. Assuming $\lambda_1 > \lambda_2$, Eq. (7) can be written as

$$2(d_1 + d) = m_1 \lambda_1 = (m_1 + 1) \lambda_2 \quad \ldots \quad \ldots \quad (8)$$

If λ is the average of λ_1 and λ_2 (so that $\lambda_1\lambda_2$ can be approximated as λ^2), then the difference of the two wavelengths, Δλ, can be expressed as:

$$\boldsymbol{\Delta\lambda = \frac{\lambda^2}{2d}} \quad \ldots \quad \ldots \quad (9)$$

Apparatus:

1. Optical Rail (1 meter)

2. Fabry-Perot setup (Fixed Mirror mount with Two Etalon)

3 Movable Mirror with Kinematic and fine linear Micrometer (0-10 mm)

4 Diode Laser mount with Kinematic (5 V) Power Supply

5 Achromatic Lens mount

6 Frosted Glass viewing Screen and mount with Micrometer

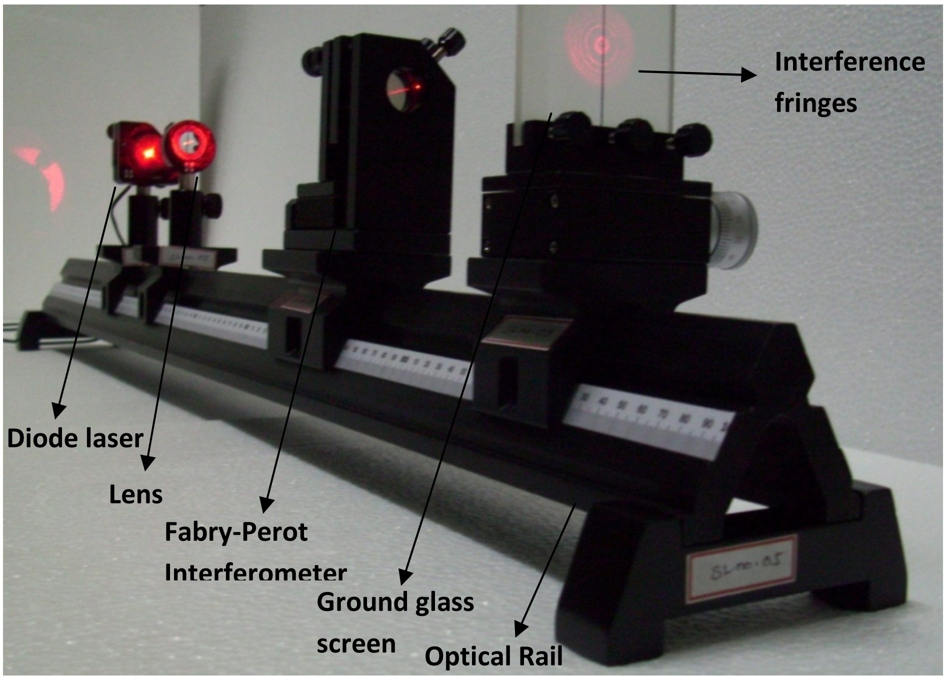

Fig 3. The Fabry-Perot interferometer set up

Procedure

I. Alignment of Fabry-Perot Interferometer to observe concentric circular fringes

1) Mount and lock the diode laser on the optical rail towards one end.

2) Mount the Fabry-Perot interferometer towards the middle of the optical rail (about 40 cm from laser). It has one fixed and one movable mirror as shown in Fig. 4.

3) Adjust the three screws behind the movable mirror to make sure that the two mirrors are visibly parallel to each other approximately. Note that two micrometer screws are attached to the interferometer, one for coarse and the other one for fine movement of the mirror. Using the coarse screw adjust the distance between mirrors to about 2mm. Use the fine screw while counting fringes.

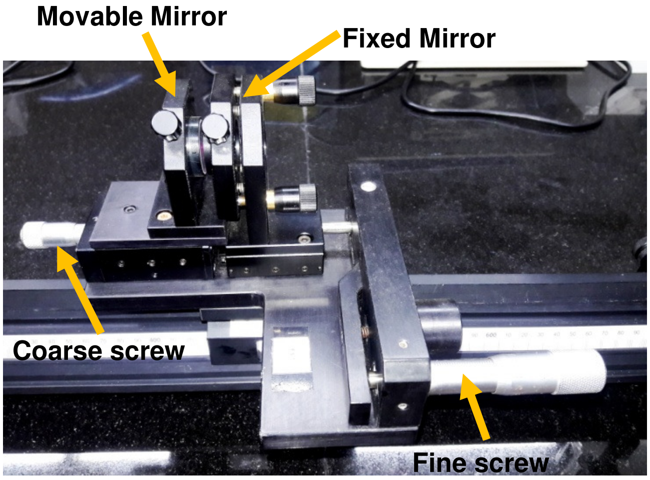

Fig. 4: Fabry-Perot interferometer

MAKE SURE THAT THE TWO MIRRORS NEVER TOUCH EACH OTHER'S SURFACES.

4) Mount the ground glass screen at the other extreme end.

5) Switch on the diode laser and adjust it such that the beam passes through the centre of the two mirrors. Adjust the two black screws (for movement in x and y directions) behind the movable mirror to let the multiple reflected beams coincide on the screen. It means both the mirrors are now nearly parallel.

6) Place a lens (f= 100mm) in front of the laser to expand the beam to create a broad source. Adjust the position of the lens so that the entire reflection cavity is illuminated. With all the components perfectly set, the observer can find a series of very intense, concentric circular interference rings on the ground glass screen.

II. Measurement of the Wavelength of a diode Laser

1) Setup the F-P interferometer as described above to observe clear circular fringes at the centre of the ground glass screen.

2) Determine the least count of the fine micrometer screw. Please note that the lever ratio is 0.03: 1, i.e. the mirror is displaced by 0.03mm for a 1mm change on the fine micrometer screw. This ratio is applicable in a limited range from 24mm downwards on the fine screw. So it is advisable to start your reading around 24mm and move the screw downwards while counting fringes. Let the initial reading be d_1.

3) Turn the fine micrometer slowly and count the number of fringes that appear (or disappear) at the centre of the ground glass screen. Record the micrometer reading d_2 after every count 10 fringes.

CAUTION: The micrometer screw is extremely sensitive. So move it very slowly to avoid collapse of many fringes while counting, which will lead to error.

4) Acquire enough data and fill up the observation table. Plot a suitable graph to get a straight line. Find slope of the graph and use Eq. 6 to determine λ.

III. Determination of difference in wavelengths of sodium doublet

1) Replace the laser with a sodium lamp and following the procedure (I) adjust the set up to get a concentric fringe pattern. You may see two sets of concentric fringes already.

2) Carefully move the mirror to see a distinct pattern where both sets of fringes coincide and record the micrometer reading. Move the mirror further (the pattern becomes splitted) till you see a distinct pattern again and record the reading. Find the difference of the two positions (2d).

3) Repeat the above step 5 times and determine average Δλ.

Observations: Least count of fine micrometer = ...

Table 1: Initial position of fine micrometer, d_1 = ...

Sl. No.	No. of fringes appaeared/disappeared **m_2-m_1**	No. of divisions rotated on micrometer	**d_2 (cm)**	**$d_2 - d_1$ (cm)**
1	10			
2	20			
3	30			
..	..			

Table 2:

Sl. No.	**Δd**	**Δλ**	**Avg. Δλ**

Graph: Plot an appropriate graph to find **λ**.

Results and discussions:

λ = …. nm

Actual value of λ = 633 nm

Precautions:

1. Do not touch or contact in any way either the front or back surfaces of the mirror pieces. Doing so will permanently damage the mirror coatings.
2. Avoid eye exposure to the direct laser beam.
3. Move the micrometer screw very slowly.

Reference: Max Born, Emil Wolf. Principles of Optics. Pergamon Press, Oxford.