Unit-11 Michelson Interferometer I

Objective：

Study the theory and the design of Michelson Interferometer. And use it to measure the wavelength of a light source.

Apparatus：

Michelson interferometer (include lens, beam splitter and mirror), He-Ne laser, screen

Principle：

British scientist Thomas Young did the experiment about interference in 1801. It was the first investigations about light interference. He let the light pass through two closely spaced narrow slits. The light would split into two parts, which is so called division of wave front. He saw the fringes on the screen at some distance behind. In order to explain this result, Thomas Young established the theory of wave optics.

Besides, using beam-splitter is another way to split the amplitude into two parts. This is so called division of amplitude which is the idea used to design the Michelson Interferometer.

A. Michelson Interferometer

As shown in figure 1, while the laser beam incident on the beam-splitter *BS* (Only the side with a reflective coating will reflect beam.), 50% of the beam, labeled as ray 1, is reflected to fixed mirror M_1 which reflects the beam back again and then passes through beam-splitter *BS*, finally, arrives at the screen *S*. The other 50% of the beam, labeled as ray 2, would pass through the beam-splitter *BS* first and then reflected back by adjustable mirror M_2. Again, beam-splitter *BS* will reflect this beam to the screen *S*.

When ray 1 and ray 2 overlap on the screen *S*, if the optical paths of two beams is different (i.e. $L_1 \neq L_2$), it would cause interference fringes. A divergence spherical wave is formed by using a convex lens. Since He-Ne laser has small divergence angle, it is hard to observe fringes on the screen. Therefore, to make the fringes clearly visible, a convex lens need to be placed between the He-Ne laser and the beam-splitter *BS*.

If $L_1 < L_2$, the virtual image M_1' formed by beam-splitter *BS* would lies in front of adjustable mirror M_2. The path difference d is the reason causes interference. If virtual image M_1' and adjustable mirror M_2 is perfectly parallel, the fringes would become perfectly concentric circles. As adjustable mirror M_2 approaches virtual image M_1', the number of fringes would decrease. If virtual image M_1' overlaps adjustable mirror M_2, fringes would disappear and replaced by a bright region on the screen. If virtual image M_1' and adjustable mirror M_2 are not perfectly parallel, the fringes would be oval-shaped.

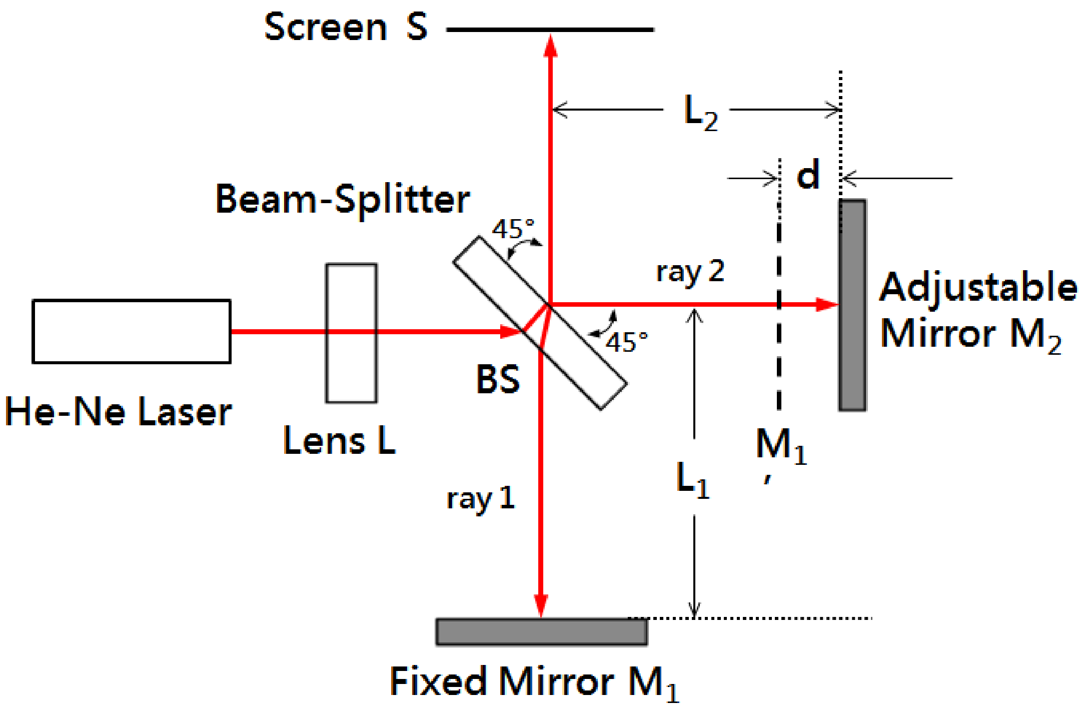

Figure 1. Michelson Interferometer set-up I

As shown in figure 2, when the distance of virtual image M_1' and adjustable mirror M_2 are large, the interference fringes generated number becomes more and smaller; when the distance of virtual image M_1' and adjustable mirror M_2 are approach, interference fringes generated number becomes less and thicker; when the distance of virtual image M_1' and adjustable mirror M_2 are overlapping, that without interference fringes on the screen; when the distance of virtual image M_1' and adjustable mirror M_2 are not parallel angle to the screen resulting interference pattern will become curved.

If d is a distance from virtual image M_1' to adjustable mirror M_2. The optical path difference is like the beam goes to-and-fro between virtual image M_1' and adjustable mirror M_2 (Note that the optical path difference is twice of the displacement of mirror.), the value is $2d$.

When laser has an angle of incidence θ, and the optical path difference becomes $2d\cos\theta$. Because of ray 1 occurs once reflection at beam-splitter interior let its phase is change, therefore the bright ring must be constructive interference on screen; the optical path difference can be expressed as

$$2d\cos\theta = n\lambda \tag{1}$$

For the same reason, when the dark ring on screen, it must be destructive interference; the optical path difference can be expressed as

$$2d\cos\theta = \left(n + \frac{1}{2}\right)\lambda$$

At this experiment, when distance is decreased from virtual image M_1' and adjustable mirror M_2 (i.e. d is decreased), and the ring-shaped interference fringe will become wider. If d is decreased until to $\lambda/2$, the ring-shaped fringe would reduce and then disappear at the fringe center. If distance is huge from virtual image M_1' and adjustable mirror M_2, we can't see the interference fringe at screen.

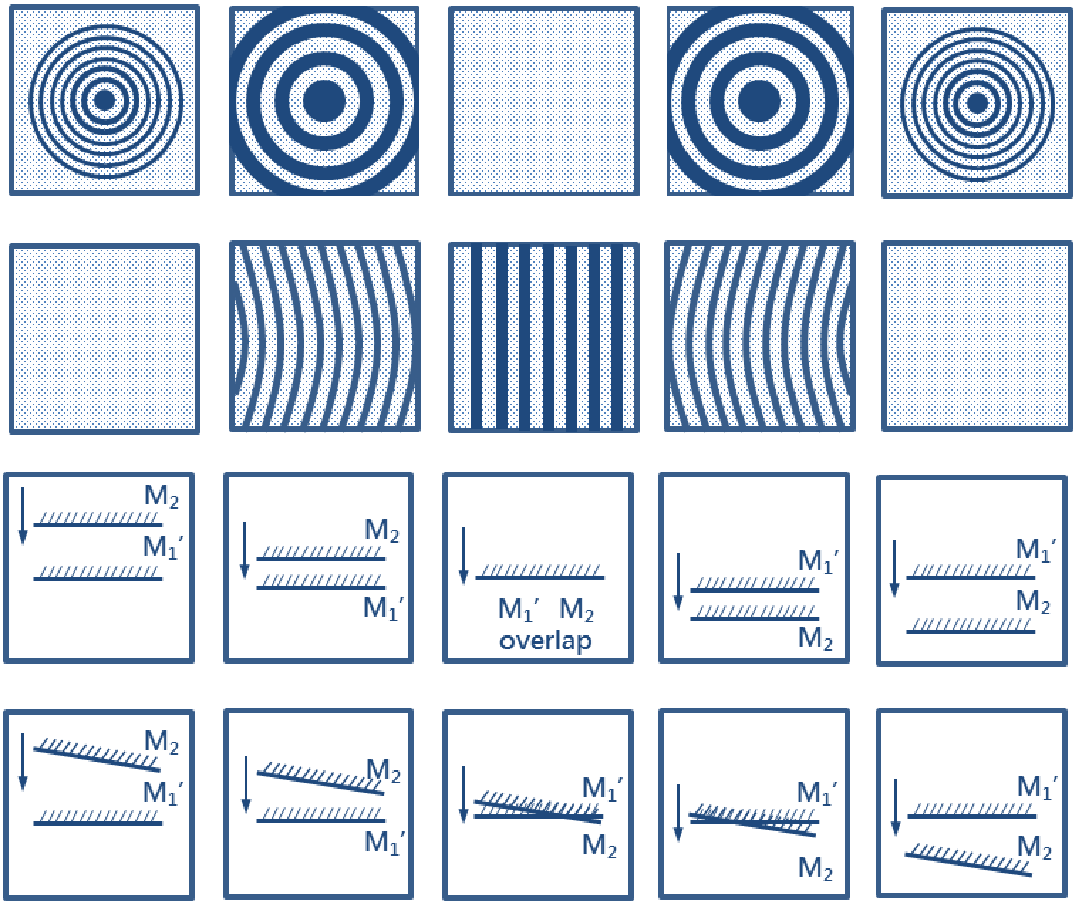

Figure 2. Interference fringe schematic

B. Measure the wavelength of a monochromatic light λ

Observe the center of ring-shaped bright fringe, let $cos\theta = 1$, from equation (1); the bright fringe equation will be expressed as

$$2d = n\lambda \tag{2}$$

If let distance d_1 from virtual image M_1' and adjustable mirror M_2, the center of ring-shaped is still bright fringe, the equation will be expressed as

$$2d_1 = n_1\lambda \tag{3}$$

As change distance d_2 from virtual image M_1' and adjustable mirror M_2, the center of ring-shaped is still bright fringe, the equation will be expressed as

$$2d_1 = n_2\lambda \tag{4}$$

Observe the variation of concentric circles interference fringes. Use equation (4) minus equation (3) would leave

$$2(d_2 - d_1) = (n_2 - n_1)\lambda \tag{5}$$

Definite $\Delta d = (d_2 - d_1)$ and $\Delta n = (n_2 - n_1)$, equation (5) will be rewritten

$$\lambda = \frac{2\Delta d}{\Delta n} \tag{6}$$

From equation (6), we know that when the distance from virtual image M_1' to adjustable mirror M_2 has changed Δd , and any position of interference fringes will change Δn on the screen. We can use this characteristic to measure the wavelength λ of the laser.

Remarks：

1. Do not look directly at an operating laser; it will cause serious eye injury.
2. Do not touch the mirror of optical element or switch on and off the laser repeatedly.
3. Make sure your laser beam won`t hurt anyone else. If you need move laser, please block the beam or turn it off first in case of any possible hazards.
4. Do not let laser emit out of your table.
5. When the experiment is conducted, do not walk beside the table in case of vibration.
6. If the fringes are not perfectly circular, it would not influence the measurement of number *n*.

Procedure：

1. Experiment set up shown in Fig. 3. (Remove the convex lens.)
2. Adjusts Michelson interferometer to keep it horizontal.
3. Adjusts the fixed mirror's screw make it parallel steady.
4. Turn on the He-Ne laser and adjust the laser holder as well as the beam-splitter position. Let the laser beam goes through the beam-splitter and then arrive the center of adjustable mirror M_2.
5. The angle of intersection of the beam-splitter *BS* and adjustable mirror or fixed mirror M_1 is 45°.
6. Adjust the fixed mirror's screw to overlap the two light spots, which reflect from the fixed mirror M_1 and the adjustable mirror M_2, on the screen.
7. Add the lens on the interferometer, this time on the screen should be possible to see the concentric circle interference fringe, If unable to see the concentric circle interference fringe, you may again trimming fixed mirror's adjustment screw, until the concentric interference fringe to appear.

8. Move the adjustable mirror M_2 back and forth by adjusting the screw micrometer. You may see the movements of the fringes. The displacement of the adjustable mirror M_2 is one twenty-fifth of the displacement of the screw micrometer.

$$\Delta s = screw\ micrometer\ tick \times 0.01 \quad \text{(mm)}$$

$$\Delta d = \Delta s \times \frac{1}{25} \quad \text{(mm)}$$

9. Move the adjustable mirror M_2 back and forth and observe the change number of fringes Δn.
10. Determine the wavelength of the laser by using the equation.

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

11. Repeat above steps.
12. Plot $\Delta d - \Delta n$ diagram, use this figure to find laser wavelength λ.

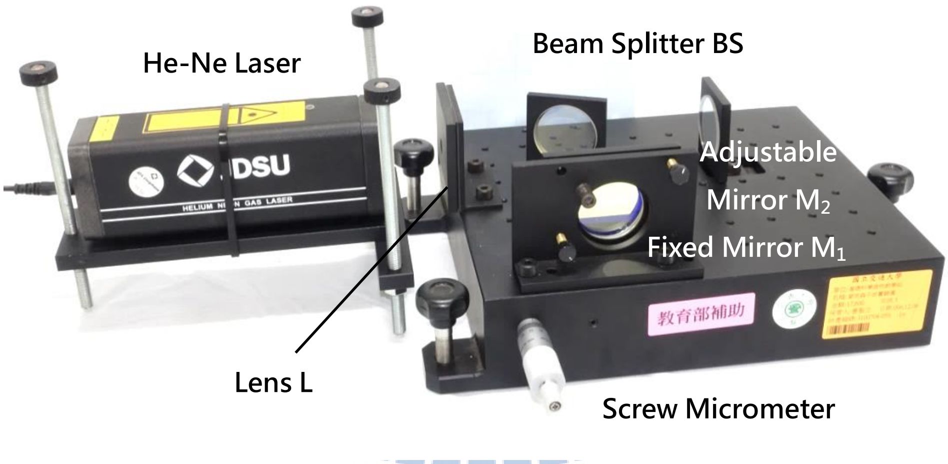

Figure 3. Experiment set-up II

Questions：

1. What is the principle of the beam splitter? How can we differentiate the coated surface? Please explain.
2. Do not change the experimental structure, only to change the wavelength of the laser, the measured interference fringes will be how to change? Please explain.
3. What are the applications of Michelson Interferometer? Please explain.