Experiment 2

Refractive index of Glass using a Michelson Interferometer setup

Theory

Division-of-Wavefront Interferometry

Coherent (single-wavelength) light from point sources two different locations in an optical beam could be combined after having traveled along two different paths. The recombined light exhibits sinusoidal fringes whose spatial frequency depends on the difference in angle of the light beams when recombined. The regular variation in relative phase of the light beams results in constructive interference (when the relative phase difference is $2\pi n$,where n is an integer) and destructive interference where the relative phase difference is $2\pi n + \pi$. The centers of the “bright” fringes occur where the optical paths differ by an integer multiple of λ_0.

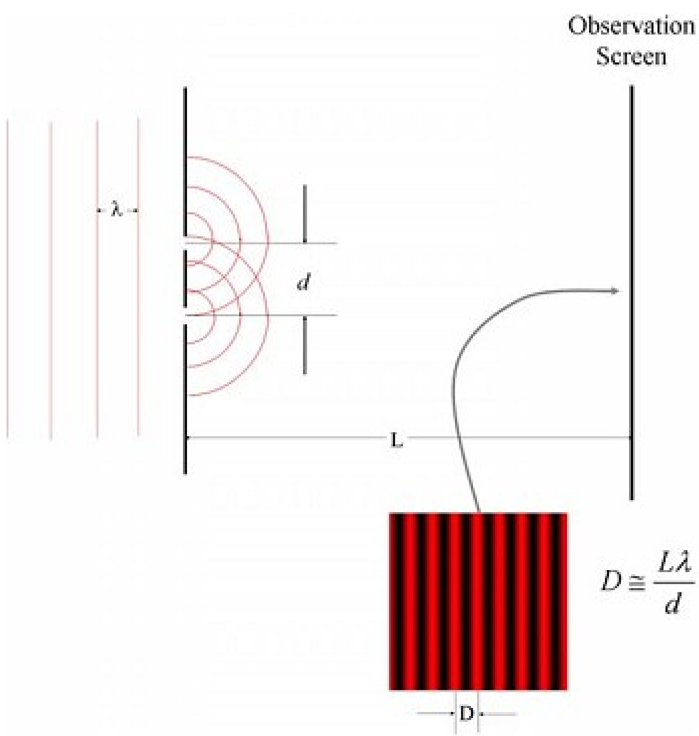

Fig 1. “Division-of-Wavefront” Interferometry via Young’s Two-Slit Experiment intensity fringes at the observation plane is D ~ Lλ/d .

Division-of-Amplitude Interferometry

This laboratory will introduce a second class of interferometer where the amplitude of the light is separated into two (or more) parts at the same point in space via partial reflection by a beam-splitter. The beam-splitter is the light-dividing element in several types of interferometers. This lab will demonstrate the action of the Michelson interferometer for coherent light from a laser.

Michelson Interferometer

The Michelson interferometer was used by Michelson when he showed that the velocity of light does not depend on the direction travelled. The apparatus is shown in Fig. 2 below. Laser light is split into two beams by the beam-splitter, which is half-silvered on the inside so that light is reflected after being transmitted through the glass. The two beams emerging from the beam splitter travel perpendicular paths to mirrors where they are directed back to be recombined at the beam-splitter surface. One mirror can be tilted by an adjustable mirror and the length of the other path may be changed by a translatable mirror. For white light sources, a compensator (a plain piece of glass of the same thickness as the beam-splitter) is placed in the beam that was transmitted by beam-splitter. The light transits the compensator twice, and thus the path length traveled in glass by light in this arm is identical to that traveled in glass in the other arm. This equalization of the path length traveled simplifies (somewhat) the use of the interferometer with a broad-band white-light source. The compensator is not necessary when a laser is used, because the coherence length is much longer than the path-length difference.

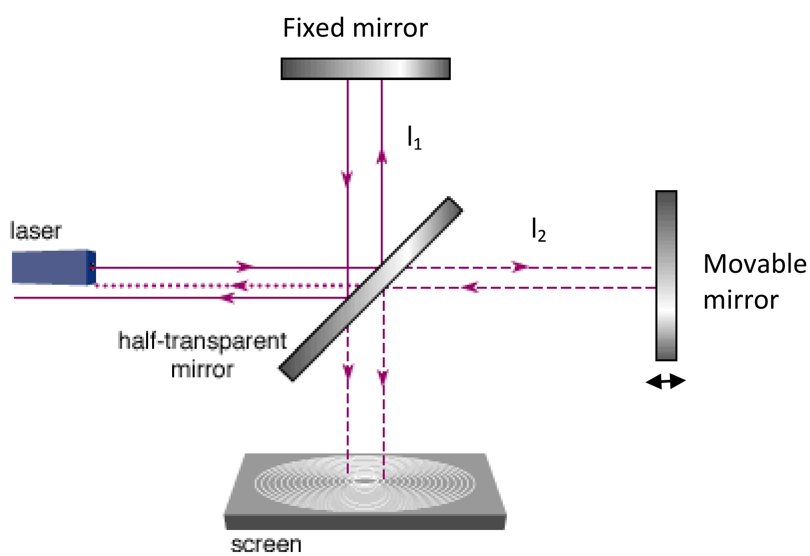

Fig 2. Schematic of Michelson interferometer

If the translatable mirror is displaced so that the two beams travel different distances from the beam-splitter to the mirror(say l_1 and l_2), then the total optical path of each beam is $2l_1$ and $2l_2$.The total optical path difference is:

$$OPD = 2l_1 - 2l_2 = 2 \cdot \Delta l \text{ [in metres]}$$

Note that the path length is changed by TWICE the translation distance of the mirror. The OPD may be scaled to be measured in number of wavelengths of difference simply by dividing by the laser wavelength:

$$OPD = 2 \cdot \Delta l/\lambda_0 \text{ [in wavelengths]}$$

We know that each wavelength corresponds to 2π radians of phase, so the optical phase difference is the OPD multiplied by 2π radians per wavelength:

$$O\Phi D = 2\pi\text{[radians/wavelength]}\cdot 2 \cdot\Delta l/\lambda_0 \text{ [wavelengths]}$$

$$= 2\pi \cdot 2 \cdot \Delta l/\lambda_0 \text{ [radians]}$$

If the optical phase difference is an integer multiple of 2π (equivalent to saying that the optical path difference is an integer multiple of λ_0), then the light will combine "in phase" and the interference is constructive; if the optical phase difference is an odd-integer multiple of π, then the light combines "out of phase" to destructively interfere.

The Michelson interferometer pictured above uses a collimated laser source (more properly called a Twyman-Green interferometer), and the two beams are positioned so that all points of light are recombined with their exact duplicate in the other path except for (possibly) a time delay if the optical paths are different). If the optical phase difference of the two beams is $2\pi n$ radians, where n is an integer, then the light at all points recombines in phase and the field should be uniformly "bright". If the optical phase difference is $(2n +1) \pi$ radians, then light at all points recombines "out of phase" and the field should be uniformly "dark".

If the collimated light in one path is "tilted" relative to the other before recombining, then the optical phase difference of the recombined beams varies linearly across the field in exactly the same fashion as in the Young's two-slit experiment. In other words, the two beams travel with different wave-vectors k1 and k2 that produce the linear variation in optical phase difference. With the Michelson, we have the additional "degree of freedom" that allows us to change the optical path difference of the light "at the center". As shown in the Fig. 3, if the optical path difference at the center of the observation screen is 0, then the two beams combine in phase at that point. If one path is lengthened so that the optical phase difference at the center is π radians, then the light combines "out of phase" to produce a dark fringe at the center.

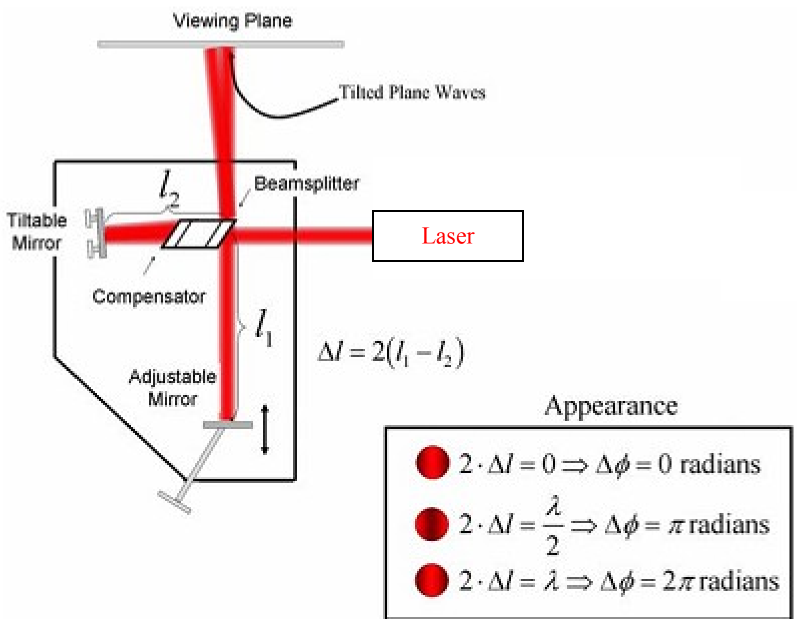

Fig 3. Michelson interferometer with collimated light so that one beam is tilted relative to the other. The optical phase difference varies linearly across the field, producing linear fringes just like Young's two-slit interference.

Interference of Expanding Spherical Waves: The strict definition of a Michelson interferometer assumes that the light is an expanding spherical wave from the source. If optical path difference is zero (same path length in both arms of the interferometer), then the light recombines in phase at all points to produce a uniformly bright field, as shown on the left of Fig. 4. However, in general the optical path lengths differ so that the light from the two sources combine at the center with a different phase difference, as shown on the right of Fig 4.

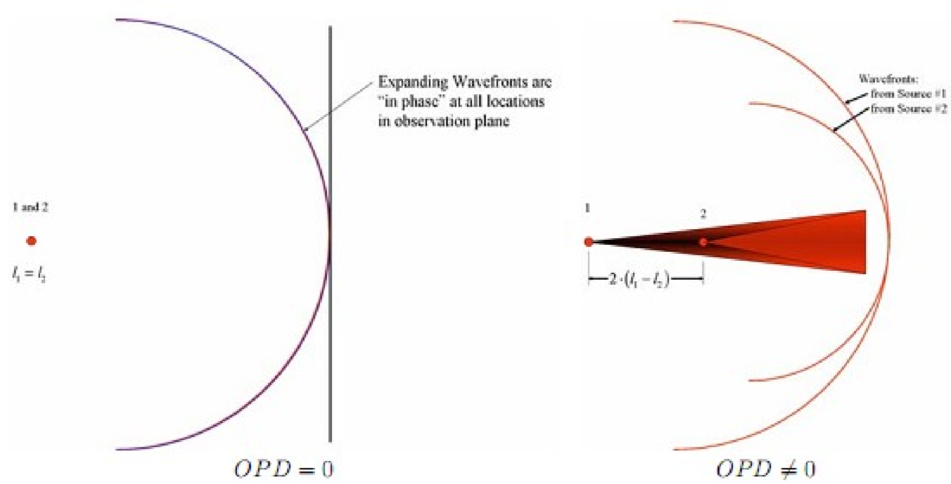

Fig 4. Michelson interferometer with path differences equal and unequal.

Thus the optical path difference varies more quickly at the edges of the observation plane than at the center, so the fringe period varies with position. In Fig. 5, the light waves recombine "in phase" at the center of the observation plane, but the period of the fringes decreases with increasing distance from the center.

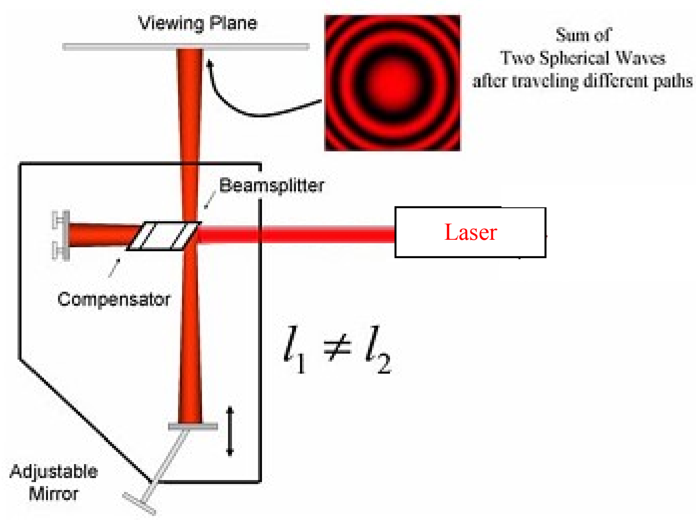

Fig 5. Michelson interferometer with spherical wavefronts traveling different path lengths.

Experiment

1. Set up the Michelson interferometer as per Fig 2. Demonstrate that you can get circular fringes on the screen [Note: To magnify the fringes, use the lens provided before the screen).

2. Put in the glass slide mounted on the rotational stage in the fixed mirror beam-path as shown in Fig 6.

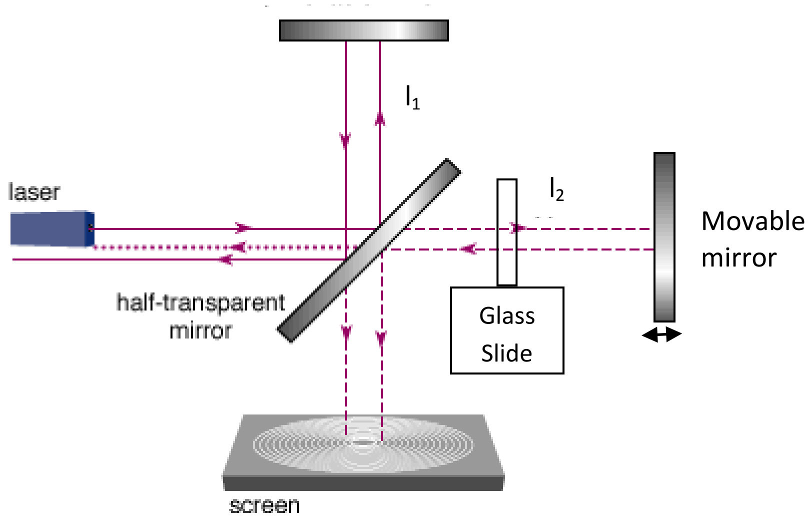

Fig 6. Michelson interferometer with glass slide in beam-path.

3. Rotate the angular stage with the glass slide so that the fringes shift. Count the number of fringes shifted with respect to a cross-mark on the viewing screen as a function of rotation angle (Note: It may be easier to count fringes a little away from the center of the pattern).

4. Calculate the refractive index n_g of the glass slide given that thickness t = 1 mm, wavelength = 650 nm, and

$$n_{\mathrm{g}} = \frac{(1-\cos\theta)\,[1-(m\lambda/2t)]}{(1-\cos\theta)-(m\lambda/2t)}\ .$$

   where m is the number of fringes shifted and θ, the inclincation angle, is defined as the angle of incidence of the beam onto the face of the glass block, i.e., the angle between the beam and the normal to the glass surface.

5. Find the value of n_g for 20, 30, 40 and 50 fringe shifts. Repeat the angular measurement for each fringe shift 5-10 times to build up statistics.

6. Also, set up an experiment for measuring coherence length of the laser supplied. Use your brains – think about coherence length, and see how you could set up the apparatus to provide you the best opportunity of estimating the coherence length. Note your efforts in detail in your lab note book. [Hint: Think about coherence length – and try to set the *maximum* path difference between the two arms in the interferometer. Note down this path difference where you can still see fringes.]

Required reading topics

1. Coherence of light sources

2. Uses of Michelson interferometer

Suggested reading topic

1. Scanning Michelson interferometer