Lab #2

Interferometry

Contents:

In this lab you will investigate the Michelson interferometer. The objectives of the module include:

1. Gain familiarity with the concepts of optical superposition and interference.
2. Learn about the properties of a Michelson interferometer.

I. Pre-Lab Activity

Make a sketch of a Michelson interferometer, similar to the figure shown later in this handout, but with notes to indicate the parts you will need. For example, label the focal length and diameter of the lenses, note the number of mirrors, and also indicate the kinds of mounts you will need (e.g., lens mount on post, mirror mount on post, mirror mount on translation stage, etc.). It doesn't have to be entirely correct; I just want you to think about what will be needed to make this drawing "come alive" on your optical table.

II. Optical Power Meter

This instrument measures the average power in an optical beam. You can operate it with one of two detectors, a silicon photodiode for visible radiation that you will use for this lab, and a germanium photodiode for near-infrared radiation. Both connect to the front of the meter using a special interface module that contains internally recorded calibration information specific to that detector. Please don't remove the interface connector from the sensor head.

To obtain a properly calibrated reading of optical power, you need to use the up/down buttons to set the wavelength to 633 nm for the red HeNe lasers.

Measurements

A) Use the optical power meter to measure the power of your HeNe laser source. Does the measurement match the number on the laser label?

B) Use the optical power meter to measure the power of the LED light in your cell phone (or you can measure the power output from the flashlight at your station if you prefer). Try to estimate the overall output power of the LED light, by considering the full size of the beam compared to the portion of the beam that the detector can actually see. How do the laser power and LED output power compare?

III. Michelson Interferometer

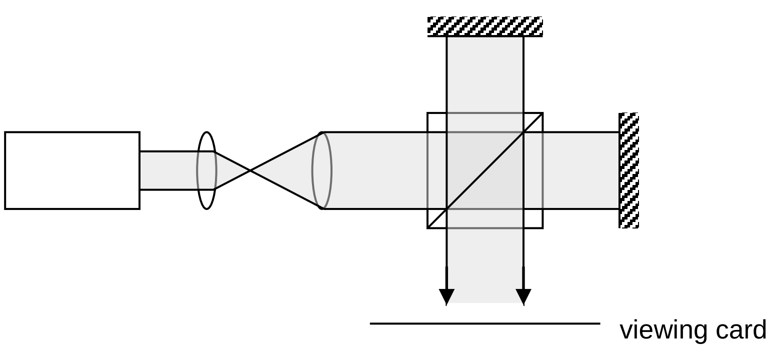

Figure 1. Michelson interferometer layout.

Construct a Michelson interferometer. First, build a beam expander for approximately 20X or 25X expansion so that you can better see the fringe patterns. This is best done by using your high-NA aspheric lens in front of the laser. Use a non-polarizing cube beam splitter and two mirrors as shown to make the interferometer. Project the output beam onto a white card. Adjust the two beams of the interferometer until you can see several fringes in the spot pattern.

A) Beam angle measurements What angular separation between the beams results in a 1-mm period fringe pattern? What angular separation gives a 4-mm period fringe pattern? Adjust for a 1 mm fringe pattern, then note how far you must turn the screw on the gimbal mirror mount to achieve a 1-mm fringe pattern after passing through infinite fringe spacing (i.e. zero optical path difference).

Calculate the rotation angle of the adjustment screw, which has 80 threads-per-inch (80 TPI), required to adjust from 1-mm fringe period on one side to 1-mm period on the other side (you will need to measure the separation between the pivot and the screw on the mirror mount to do the calculation). Does it agree with the adjustment you observed in the lab?

B) Microscope slide parallelism Adjust the interferometer for a uniform spot (no fringes visible in the interference pattern, only a spot that winks on and off). Insert a microscope slide into one arm of the interferometer. Observe the fringe pattern that results at various positions on the slide. Choose a representative location and measure the fringe separation on a viewing card.

Based on the observed fringe separation, calculate the angle between the two faces of the microscope slide.

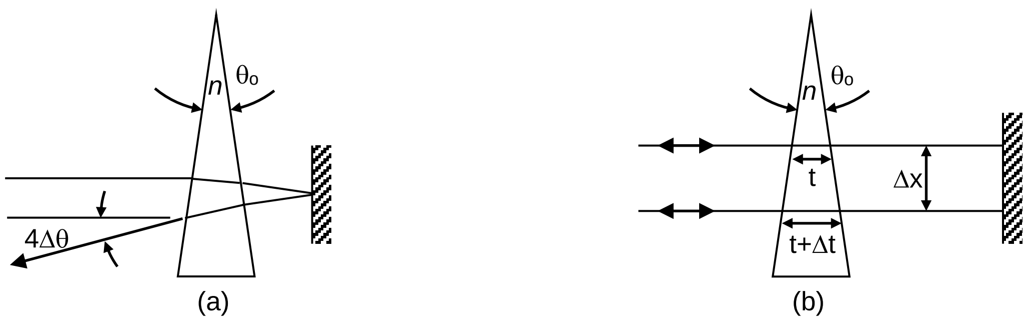

Figure 2. Two views of the effect of a prism on a light beam in the paraxial limit.

You can calculate the angle from two different but equivalent points of view. In Figure 2(a), the slide is treated as a prism. In the small-angle approximation the beam is deflected from its original path by an incremental angle $\Delta\theta = \theta_o(n-1)/2$ at each air/glass interface (prove this to yourself), where θ_o is the apex angle of the prism. After 4 passes the beam takes on an angle $4\Delta\theta$, leading to a fringe spacing of $\lambda/\Delta\theta = \lambda/2\theta_o(n-1)$.

Equivalently, you may view the beam as being delayed differently by different portions of the prism, as illustrated in Figure 2(b). In this case the two portions of the beam pass through different glass thicknesses with a differential optical path length OPL=$2(n-1)\Delta t$, where the factor of 2 comes from the beam passing through the glass twice. The thickness Δt is related to the fringe spacing Δx and the apex angle θ_o by $\Delta t=\theta_o\Delta x$, so the differential OPL is $2(n-1)\theta_o\Delta x$. This OPL difference (Optical Path Difference, typically called "OPD") equals λ for two neighboring fringes, or $\lambda=2(n-1)\theta_o\Delta x$. Rearranging, we get the fringe spacing $\Delta x=\lambda/2(n-1)\theta_o$. This is the same result we got from the other viewpoint. We'll examine the equivalence of a tilted beam to a beam with a linear phase variation in class.

C) Vibration Measurement Adjust for a uniform spot (no fringes), and measure the optical power in the beam. You may wish to place an iris in front of the power meter. An accurate measurement of the interference effect requires that the detector area be significantly smaller than the size of a fringe. Connect the analog output from the power meter to the oscilloscope so that you can observe dynamic changes in the output of the interferometer. Look at the waveforms you get by tapping or scratching the table or gently pushing on one of the mirrors. Try to observe your voice or other sounds that vibrate the mirror. You should be able to generate a sine wave by singing in a low register (the higher harmonics are not well transduced with the rigid mirror mounts, so you get a pretty good sine wave no matter how complex your actual voicing is). Use the FFT function on the oscilloscope (the ***math*** button) to display the sound spectrum. Sketch and explain what you see.

D) Fringe Contrast Using the output from the oscilloscope, measure the fringe contrast you are able to get. The fringe contrast is defined as $\frac{(I_{\max} - I_{\min})}{(I_{\max} + I_{\min})}$. (Hint: Use the persistence feature on the oscilloscope, without averaging, and push on one of your mirror mounts to generate fringes that go through $I_{\max}$ and $I_{\min}$). Measure the power in each arm of the interferometer, by blocking one arm at a time. Does the contrast calculated using the interferometer equation agree with the measured contrast?

Now insert a neutral density filter of approximately 0.3 OD (optical density) into one arm of the interferometer. Measure the power in that arm, and then measure the fringe contrast again. Explain your results using the interference equation. (Remember the beam passes through the filters twice, so the actual attenuation will be double the advertised values).

E) (optional) Coherence Length of Laser A fundamental assumption of our interferometer analysis so far has been single-frequency operation. In reality, no laser is truly single frequency, but consists of a continuum of frequency components with randomly varying phase terms. We characterize this property by considering the coherence time of the laser (more often expressed as a *coherence length* which is the coherence time times the speed of light). This coherence time is the width of the laser's autocorrelation function, and it is inversely proportional to the spectral width of the source. A perfect sine wave has an infinite coherence time. Random noise has an infinitesimal coherence time.

For an interferometer, the coherence time, or coherence length, is fundamentally important, since relative delays in the two arms of the interferometer must be less than the coherence time, or length, of the source to see fringes. White-light interferometers (with broad spectral sources that have very short coherence times) may require the two paths of the interferometer to be matched to within a few micrometers! Other lasers may have coherence lengths of several hundred meters.

When the path difference is equal to half the coherence length of the laser, your fringe contrast will decrease to half its nominal value. Measure the fringe contrast of your interferometer as a function of differential path length, by unbalancing the two arms. Use one very short path, and another path that you can vary. The coherence length of the HeNe laser should be on the order of meter(s*).* Try to make two measurements with differential paths of 1 and 2 meters respectively. Interpolate from your results to estimate the coherence length of the laser.