Lab #4

Gaussian Beams

(1 week)

Contents:

1. Summary of Measurements

Gaussian Beam Spot Size and Divergence

1. Use the razor blade chopper to measure the spot size of the HeNe laser beam vs. distance. Use your results to describe the location of the waist of the beam, and the Rayleigh range and waist spot size.
2. Focus a 20x expanded beam with a short focal length doublet (*f* = 50 mm) and measure the beam waist using the chopper technique.
3. Repeat the measurement with the lens reversed.
4. Repeat the measurement with a plano-convex singlet (*f* = 50 mm).

Beam Profile

5. Use the CCD camera to observe the laser beam vs. distance. Observe the beam clipped with an aperture in both the near field and the far field.

2. New Equipment

1. **SRS chopper** The SRS chopper is used for beam modulation, often in conjunction with a lock-in amplifier for sensitive, low noise measurements. In this experiment we are using it to profile the Gaussian beam. There are two different chopper wheels provided, with chopper frequencies up to 4 KHz possible (using the wheel with 30 slots). The speed is set using the potentiometer on the front panel and the frequency range switch to the left of the speed knob. Two synchronization signals are provided for interfacing to a lock-in or other instrument. You will use the far-right sinc output, with the toggle switch set to “diff”. In this configuration the output is a short pulse once per revolution. For the beam profile measurement we have affixed a razor blade to the chopper wheel to provide a clean edge for the measurements.
2. **Large area photodetector** In order to capture all of the light that passes the chopper we will be using the variable-gain large area photodetector (Thorlabs PDA100A2, 9.8 mm Φ active area). This Silicon photodiode is coupled to a variable-gain transimpedance amplifier. Please use the 0 dB gain setting for today’s lab, which should provide a measurement bandwidth of about 11 MHz. You may familiarize yourself with this detector using the manual that is linked to the EELE 482 webpage.

3. Introduction

The purpose of this lab is to investigate the properties of Gaussian beams, as well as the focusing properties of different types of lenses. You will become familiar with the very useful chopper measurement technique for making accurate measurements of very small focused Gaussian beams. You will also view the beam using the CCD camera, and observe the effects of an aperture on the beam in both the near field and the far field.

4. Gaussian Beam Profile of the HeNe Laser

We can characterize a Gaussian beam by one parameter, such as the beam waist size w_o, provided we know the location of the waist in z and the wavelength of the beam λ. We know the wavelength of the beam for the HeNe laser is λ = 632.8 nm. Determination of the location of the waist and w_o thus requires at least two measurements. In practice, a more accurate determination is made by measuring the beam at several locations and fitting the results to the hyperbolic expression for w(z).

You can measure the beam using a ccd camera like we used to observe diffraction patterns. For an unfocused beam this provides accurate 2-dimensional data for the beam intensity. The pixel spacing (few μm per pixel) prevents the use of this technique for tightly focused beams. Even for broad beams, a more rapid measurement can be made using a rotating chopper to obscure the beam while measuring the beam power beyond the chopper using a photodetector. The intensity is displayed on an oscilloscope, and the fall time is a direct measure of the beam size. It is shown in Suzaki and Tachibana that the time required for the power to drop from 90% to 10% of its full value (the 90%-10% edge width) is related to the Gaussian spot size according to

$$w = 0.7803\omega r(t_{10} - t_{90})$$

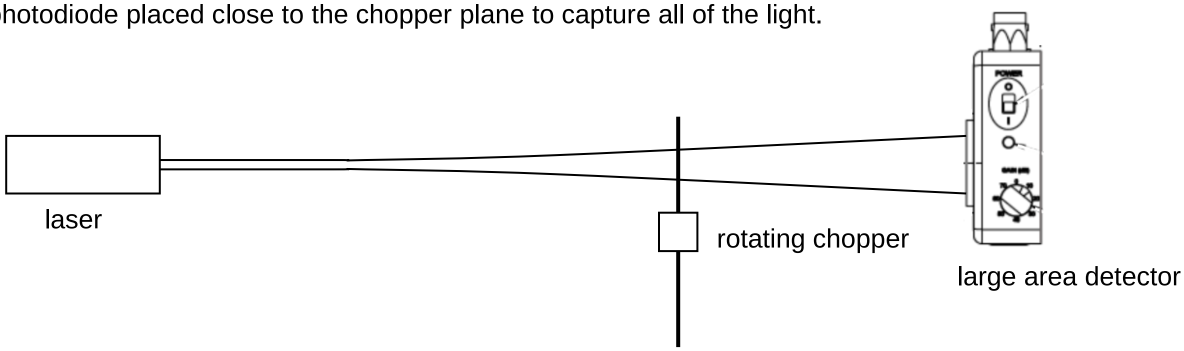
where $\omega = 2\pi/T$ and T is the period of one revolution of the chopper wheel. The method can be accurate to 1% or better for a stable chopper and a known Gaussian beam profile. Aberrated beams can lead to misinterpretation of the measured edge width. If there is significant clutter in the wings of the beam, the edge may be distorted near the top or bottom, and sometimes a 20%-80% measurement is more robust. If you use the 20%-80% measurement, the proper scale factor is given by

$$w = 1.19\omega r(t_{20} - t_{80}).$$

A perfect beam should yield the same value for w using either the 10%-90% or the 20%-80% measurement.

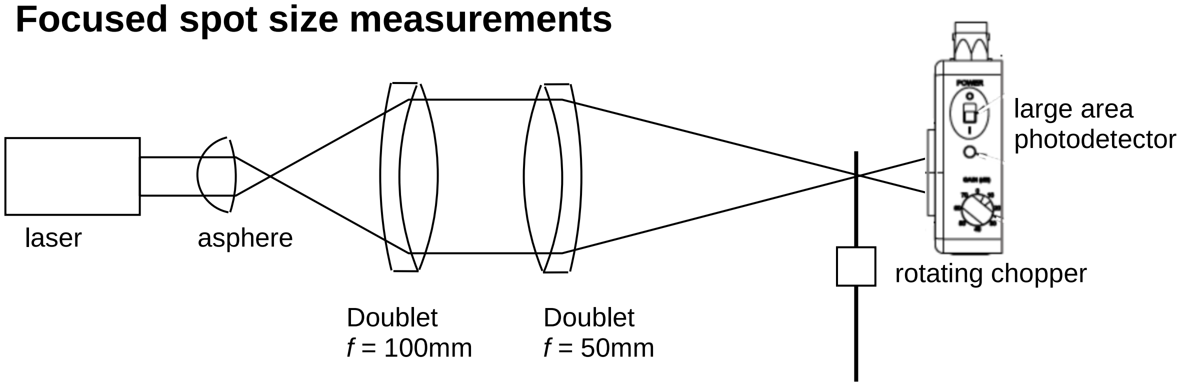
The chopper surface needs to be straight on a scale commensurate with the spot size. We will use the SRS chopper for this measurement, with a razor blade affixed to the chopper wheel to provide an accurate edge for our measurements. **Don't run the chopper faster than 10 Hz.** We don't need razor blade projectiles in the lab.

It is important to capture all of the light that passes the chopper. This can be accomplished with a lens behind the chopper wheel that focuses the light onto the detector. Alternatively we can use a large area photodiode placed close to the chopper plane to capture all of the light.



a) Use the chopper method to measure the beam spot size of the HeNe laser at several positions along the beam. Fit your measurements to the ideal expression for the variation of w(z) in order to predict w_o and the location of the waist of the beam relative to the output face of the laser. You may need to use one or two mirrors to fold the beam, in order to make measurements significantly distant from the laser endface. Plot your data with your best fit theoretical curve.

5. Focused spot size measurements



a) You will need to expand the laser beam for these measurements. Use a Thor Labs CM230 asphere (*f*=4.5mm) as the primary lens and a 100mm focal length achromatic doublet lens as the secondary. Be sure the more strongly curved face of the doublet lens is away from the focused spot. Use a short focal length achromatic doublet (*f* = 50 mm) as the test lens for your measurement. Mount the chopper on a z-translation stage so that you can easily locate the position of the best focus. What is the spot radius at the beam waist, beyond the doublet lens? Is the beam diffraction limited (in other words, does it measure close to what you expect for a perfect Gaussian beam)?
b) Repeat the measurement with the 50mm doublet turned around. Compare the measurement to part (a).
c) Repeat the measurement with a 50mm plano-convex singlet. Compare the measurement to the previous two. Comment on the choice of lens type for achieving a tight focus of the beam.

6. Beam profile (do this is you have time)

(a) Using the CCD camera observe the 2-D profile of the laser beam. Describe how the 2-D profile is affected in both the near field and the far field when an aperture is introduced that "clips" the Gaussian beam.

7. References

1. This lab write-up has been written with liberal use (including huge portions lifted from) Marty Fejer's lab notes for Applied Physics 304, Winter 1991, Stanford University.
2. H. Kogelnik and T. Li, "Laser Beams and Resonators," Applied Optics, **5**, p.1550, 1966.
3. Y. Suzaki and A. Tachibana, "Measurement of the μm sized radius of Gaussian laser beam using the scanning knife edge," Applied Optics, **14**, p2809, Dec. 1975.
4. A. E. Siegman, "Lasers," University Science Books, 1986.