Gaussian Beam Optics

Determining the intensity profile of a refracted laser beam

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Theory

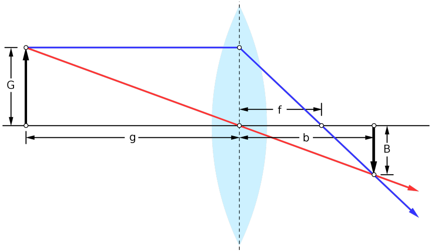


Figure 1: The focal point of a thin lens[1].

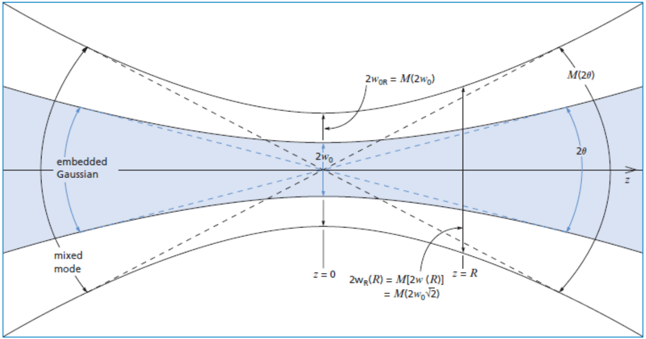


Figure 2: A beam and its embedded Gaussian beam[2].

[1] M. Run, Thin Lens Formula, Wikipedia (2019)
[2] CVI Melles Griot, Gaussian Beam Optics, Technical Guide 2009, 2, 1 (2009)

Theory

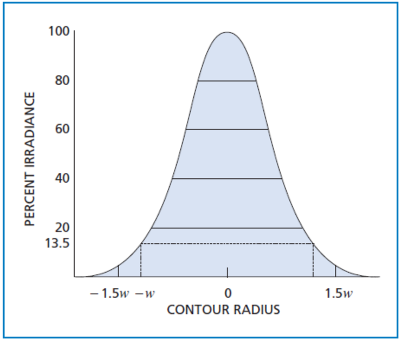


Figure 3: The radial Gaussian intensity profile $I_z(w)$ of TEM_{00}[3].

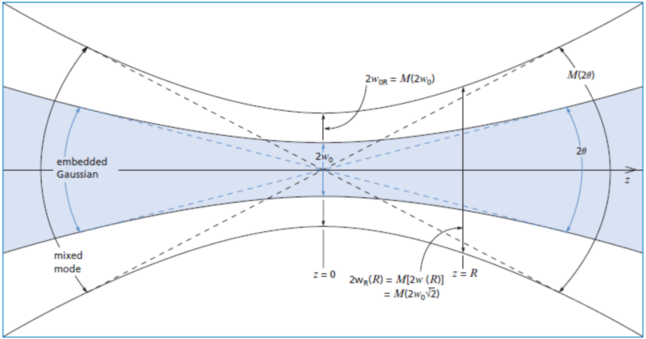


Figure 4: A beam and its embedded Gaussian beam[3].

[3]CVI Melles Griot, Gaussian Beam Optics, Technical Guide 2009, 2, 1 (2009)

Theory

- $I_z(w)$ is Gaussian for all z for TEM$_{00}$.
- $w(z) = w_0\sqrt{1 + \left(\frac{z\lambda M^2}{\pi w_0^2}\right)^2}$

- M^2 quality factor
- Gaussian Beam: $M^2 = 1$
- Real laser: $1.1 < M^2 < 1.3$
- Study of non-lineair absorption of clusters[4]

[4] Su Z. et al, Nanoscale, 14, 3618. (2022)

Aim

- Check if our laser beam is Gaussian.
- Determine M^2 for two wavelengths.

Setup

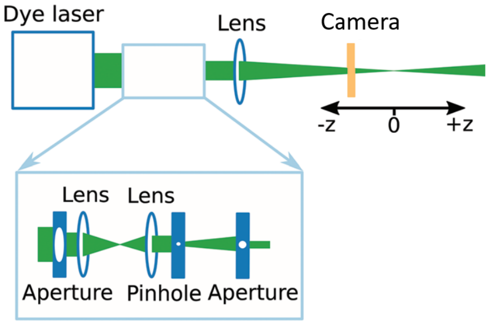


Figure 5: Schematic representation of the experimental setup[5].

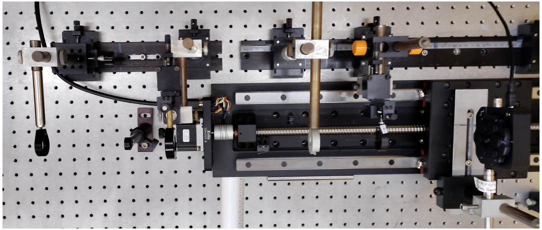


Figure 6: The experimental setup including the camera on the motorized linear stage.

[5] Su Z. et al, Nanoscale, 14, 3618. (2022)

Laser

- Quanta-Ray pulsed Nd:YAG (532 nm) pumped Sirah Cobra Stretch dye laser system
- $\lambda_1 = 600\,\mathrm{nm}, \lambda_2 = 570\,\mathrm{nm}$

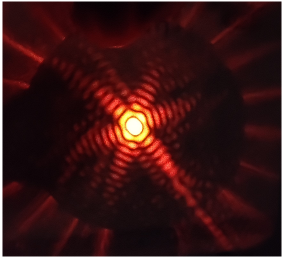


Figure 7: The beam profile.

Figure 8: The used Nd:YAG laser (left) and the dye laser (right).

Camera

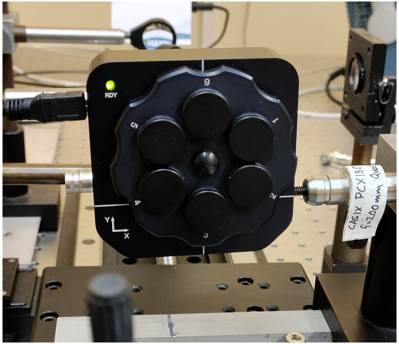


Figure 9: Thorlabs BC106N Beam Profiler.

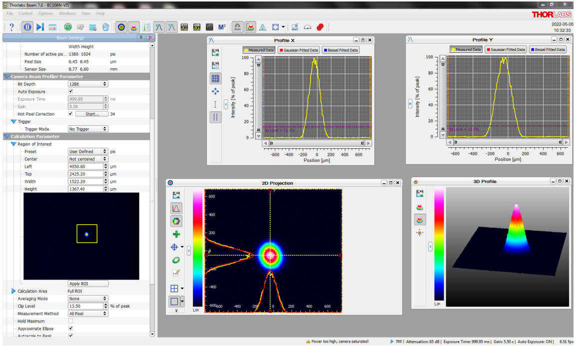


Figure 10: Thorlabs Beam 7.7 (Beam Analyzing Software).

Measuring the profile: fitting Gaussians

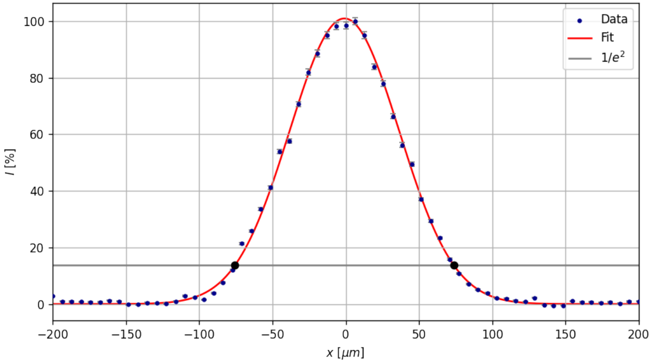


Figure 11: Gaussian profile data of the beam for $z = 17\,\mathrm{cm}$ in the x-direction, along with fit.

$$I = Ae^{\frac{(z-\mu)^2}{2\sigma^2}}$$

$$w(z) = 2\sigma(z)$$

Measuring the profile: error analysis $I(x), I(y)$

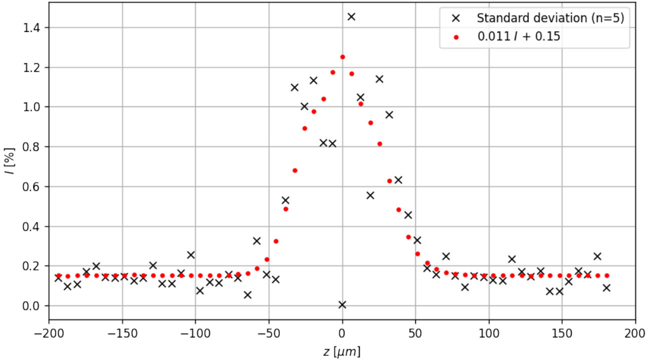


Figure 12: Standard deviation in repeatedly measured data for $z = 9\,\mathrm{mm}$ ($n = 5$).

Measuring the profile: error analysis $w(z)$

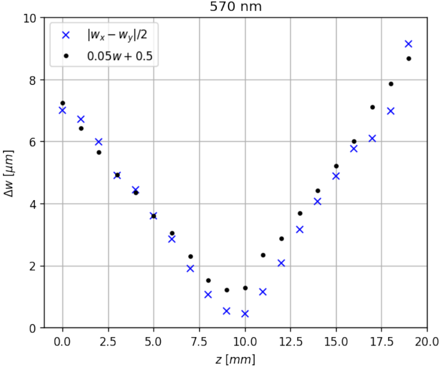


Figure 13: Difference between w measured in the x and y direction (570 nm).

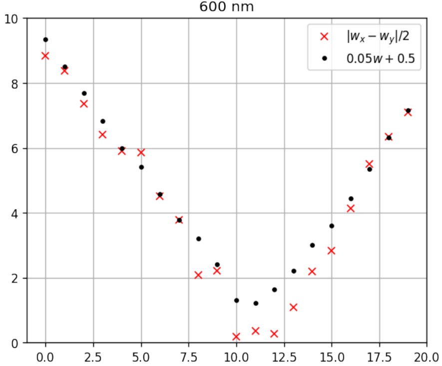


Figure 14: Difference between w measured in the x and y direction (600 nm).

Measuring the profile: fitting $w(z)$ ($\lambda = 600\,\mathrm{nm}$)

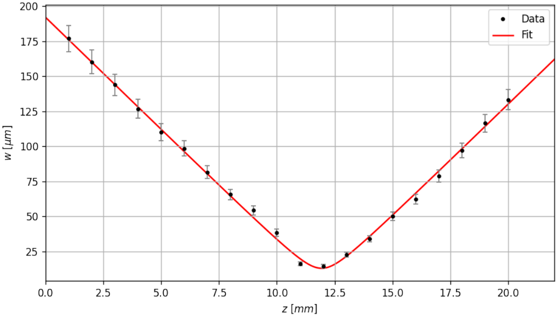


Figure 15: Measured laser profile along with fit for $\lambda = 600\,\mathrm{nm}$. $\chi^2_{red} = 1.18$, $p = 0.265$.

$$w(z) = w_0 \sqrt{1 + \left(\frac{z - z_0}{z_R}\right)^2}$$

$$w_0 = (13.0 \pm 0.3)\ \mu\mathrm{m}$$

$$z_0 = (11.9 \pm 0.1)\ \mathrm{mm}$$

$$z_R = (0.81 \pm 0.02)\ \mathrm{mm}$$

$$M^2 = \frac{\pi w_0^2}{z_R \lambda} = 1.09 \pm 0.06$$

Measuring the profile: fitting $w(z)$ ($\lambda = 570\,\mathrm{nm}$)

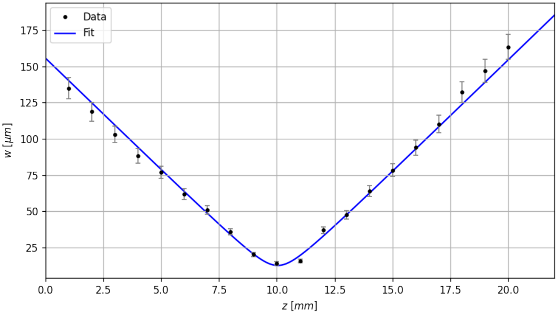


Figure 16: Measured laser profile along with fit for $\lambda = 570\,\mathrm{nm}$. $\chi^2_{red} = 1.35$, $p = 0.149$.

$$w(z) = w_0\sqrt{1 + \left(\frac{z - z_0}{z_R}\right)^2}$$

$$w_0 = (12.7 \pm 0.3)\ \mu\mathrm{m}$$

$$z_0 = (10.0 \pm 0.1)\ \mathrm{mm}$$

$$z_R = (0.82 \pm 0.02)\ \mathrm{mm}$$

$$M^2 = \frac{\pi w_0^2}{z_R \lambda} = 1.08 \pm 0.06$$

Discussion: Chromatic Aberration

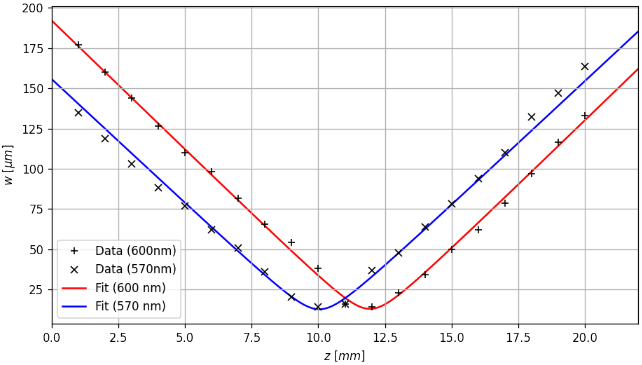


Figure 17: Data and fits for both wavelengths together: notice the shape is nearly identical, but the focal point has shifted due to chromatic aberration.

Conclusion

1. Gaussian beam approximation holds
2. $w(z)$ behaviour corresponds with theory ($p = 0.265, p = 0.149$)
3. $M^2(600\,\mathrm{nm}) = 1.09 \pm 0.06$, $M^2(570\,\mathrm{nm}) = 1.08 \pm 0.06$
4. Compatible with each other and suited for high precision experiments
5. Main source of errors: angular distribution

References

[Run, 2019] Run Mike (2019)

Thin Lens Formula

Wikipedia, `https://commons.wikimedia.org/wiki/File:Thin-lens-formula-part1_DE.svg`.

[CVI, 2009] CVI Melles Griot (2009)

Gaussian Beam Optics

Technical Guide 2009, 2, 1.

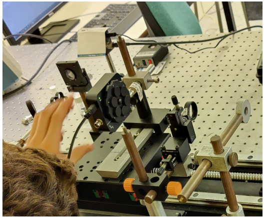
[Su, 2022] Su Z. et al. (2022)

The wavelength-dependent non-linear absorption and refraction of Au_{25} and Au_{38} monolayerprotected clusters

Nanoscale 2022, 14, 3618.

Methods

1. Align the camera.
2. Adjust z to the desired value.
3. Uncover the laser and calibrate the camera.
4. Aim the crosshair on the peak value.
5. Collect the data.
6. Repeat for several values of z.



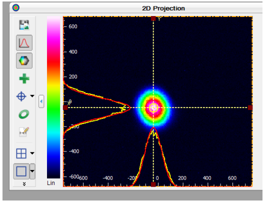


Figure 18: The camera alignment and software.