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Titanium-Doped Sapphire Crystal Laser Construction

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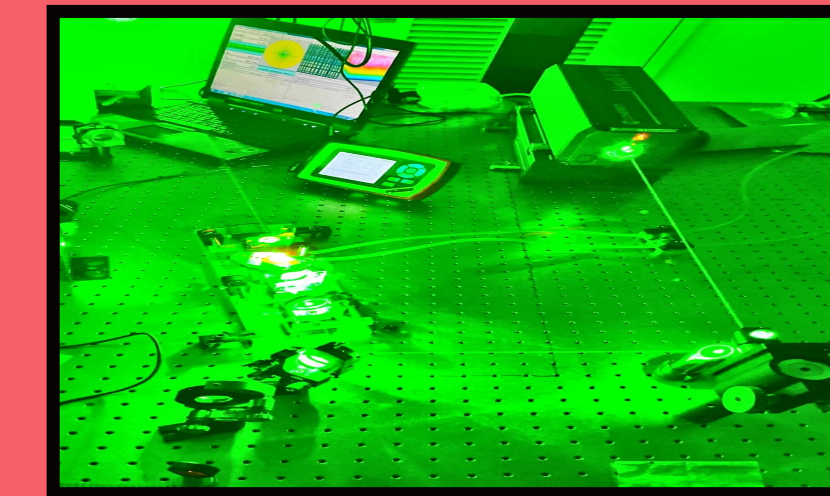

Introduction

This summer project was to learn about how lasers work, and then to build and test a laser capable of producing very short pulses of light. Lasers have innumerable applications including information processing, material cutting, surgery and spectroscopy.

The word laser is an acronym: Light Amplification by Stimulated Emission of Radiation. As sketched in Fig. 1, atoms have quantization or integer allocation of energy. They can be excited into a higher energy state by absorbing a photon and then emit this energy spontaneously in the form of another photon. Stimulated emission occurs when a photon causes an already exited atom to emit an identical photon.

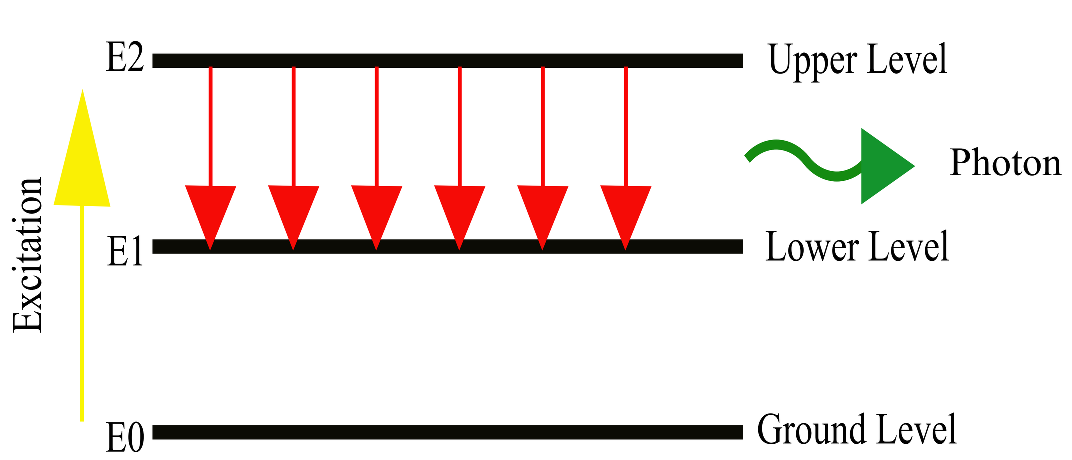

Fig. 1[1]: Spontaneous emission resulting from energy level transition.

Lasers use mirrors to send these photons back and forth, amplifying itself within its oscillatory cavity. A laser typically has one mirror that is highly reflective, and another that allows transmission of some fraction of the photons. This then deposits a directional and intense beam.

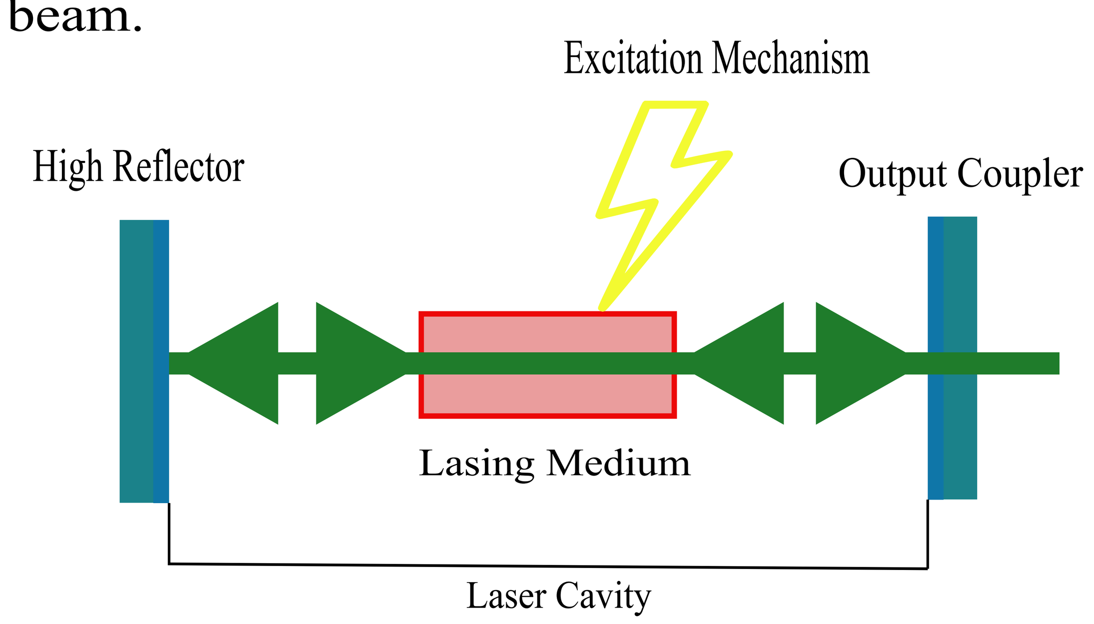

Fig. 2[1]: Fundamental laser components.

Construction and Performance

The lasing material in this project was a sapphire crystal with some titanium atoms added to give it a broader range of energy levels. Titanium-doped sapphire (Ti:S) is capable of producing a large range of wavelengths. The excitation mechanism in this case was the Verdi laser. It excited or "pumped" the Ti:S crystal. Its green light focused into the crystal, which caused the Ti:S to emit light at the red end of the spectrum. Figure 3 shows two curved mirrors which collect the red light, circulating it between the high reflector and output coupling mirror, and focusing it again in the Ti:S.

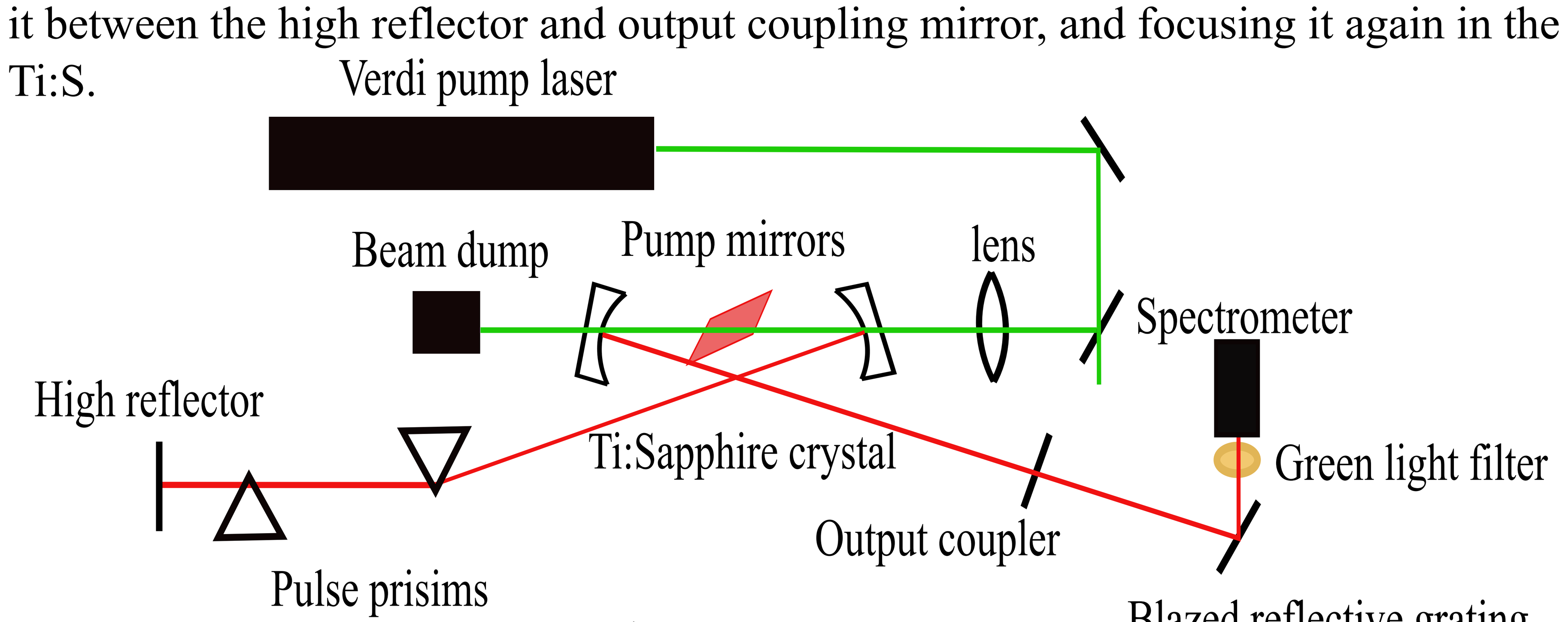

Fig. 3[1]: Ti:Sapphire laser schematic.

Much time was spent positioning the optical elements such that the red beam coincided with the green beam in size and location within the crystal. Figure 4 showcases the continuous wave operation performance.

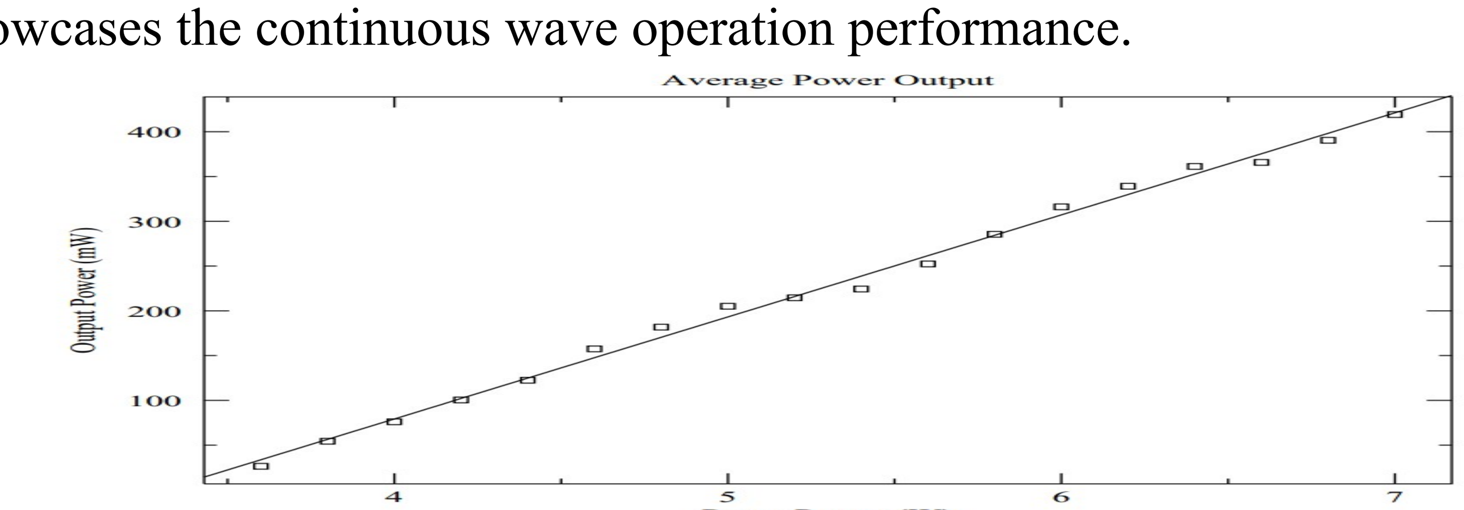

Fig. 4[1]: Ti:Sapphire CW performance, (output power as a function of pump power).

Using a blazed reflective grating, the laser was able to alter the wavelength λ. A reflective grating strongly reflects different wavelengths in different directions. By rotating this, I was able to reach a range Δλ from 743 to 865 nanometers. Figure 6 showcases ~ 30 x 10^-15 second duration pulsing when the laser amplifies all possible wavelengths and is "mode locked".

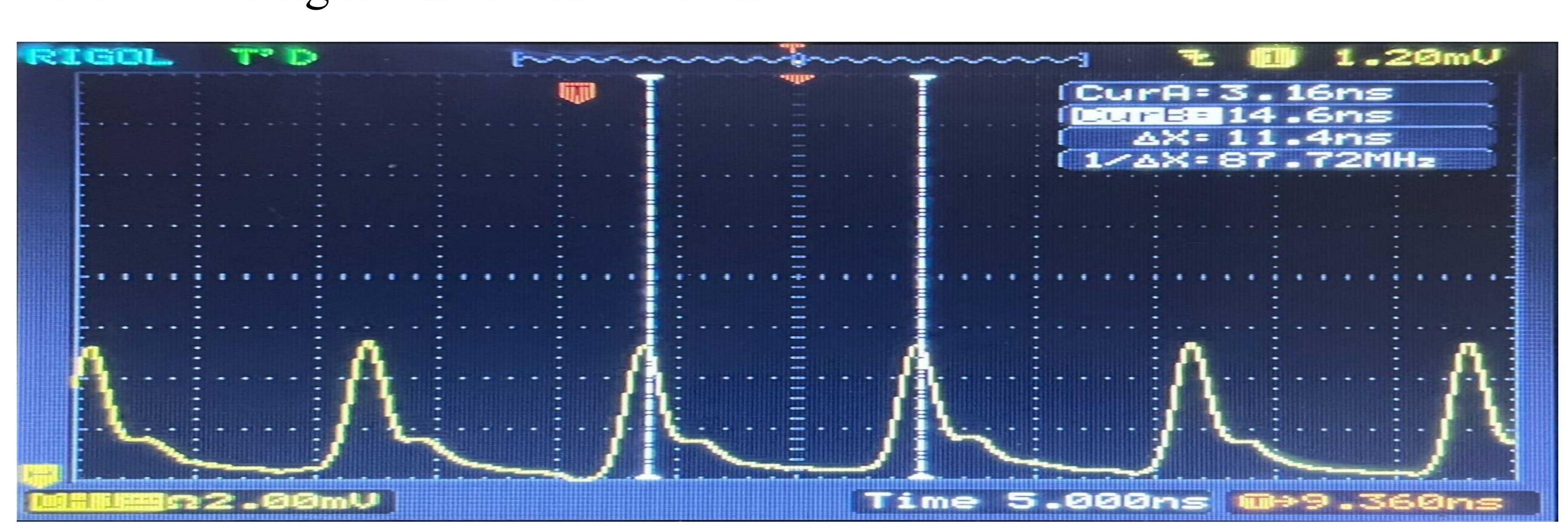

Fig. 5[1]: Ti:Sapphire pulsed performance. Each pulse lasting ~30 fs and circulating the laser cavity every ~11.4ns

Pulsed Theory

Since the Ti:S laser can amplify over a long range Δλ, it is possible to combine many of these wavelengths into extremely short pulses. It is necessary to have all wavelengths travel around the laser cavity in the same amount of time. Figures 6 and 7 show how the speed of light varies with wavelength in a material such as the Ti:S crystal, and causes refraction at different angles (Fig 7. Snell's law).

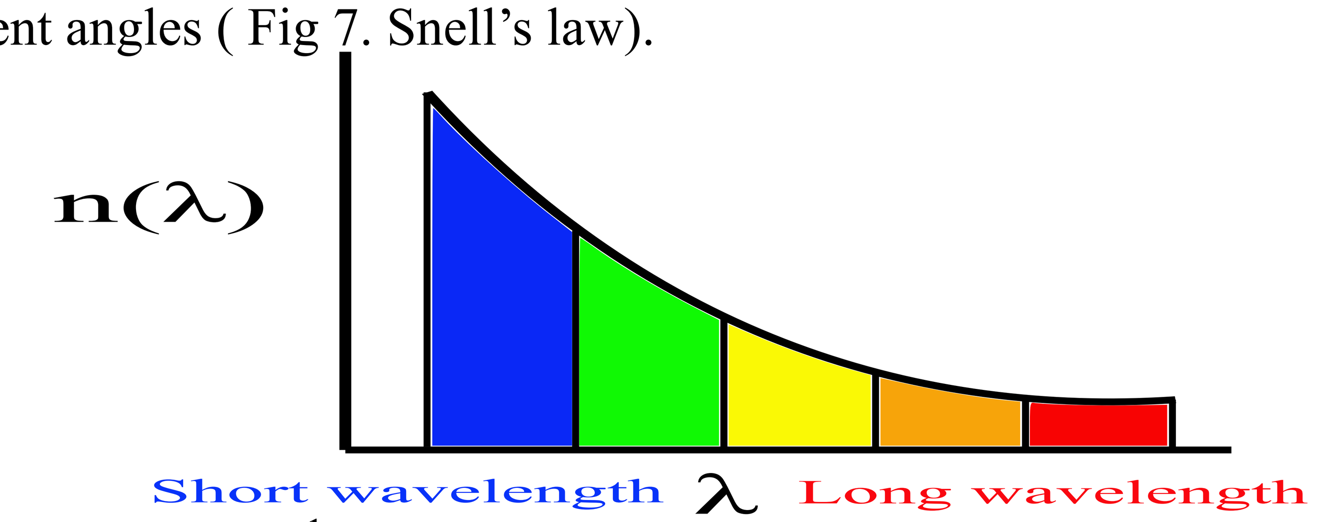

Fig. 6[1]: Index of refraction (n) as a function of wavelength.

$(2)^2$ $n_1 \sin[\theta_1] = n_2 \sin[\theta_2]$

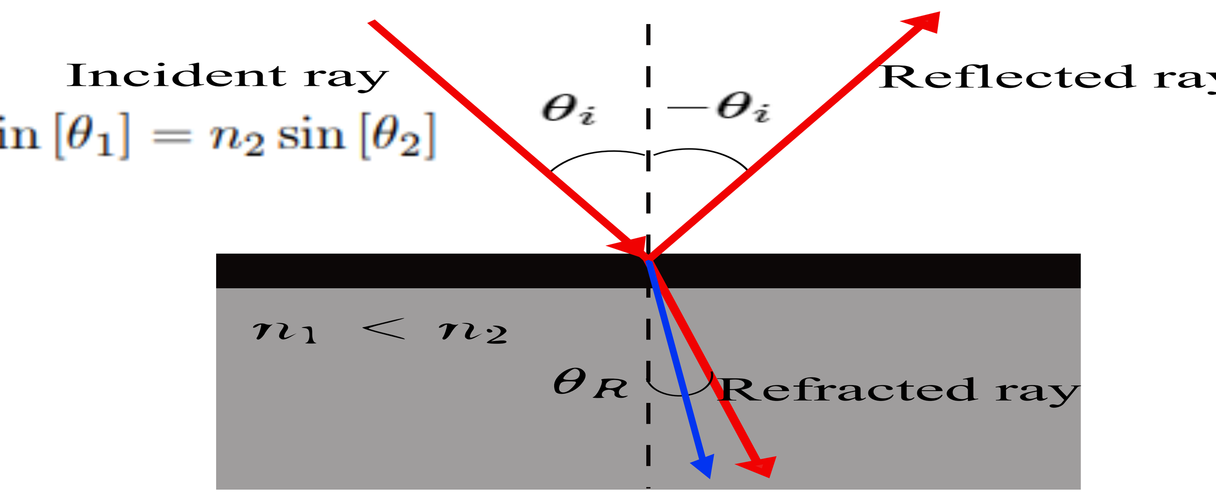

Fig. 7[1]: Snell's law visualized. When the index of refraction in medium 2 is larger, the ray bends in accordance to (2) . A shorter wavelength is bent more, resulting in a separation.

The speeds of different wavelengths in Ti:S are compensated using two prisms (included in Fig.3). Figure 8 shows how the prisms are arranged: one disperses the different wavelengths, and the other delays each wavelength by the proper amount as it travels through glass.

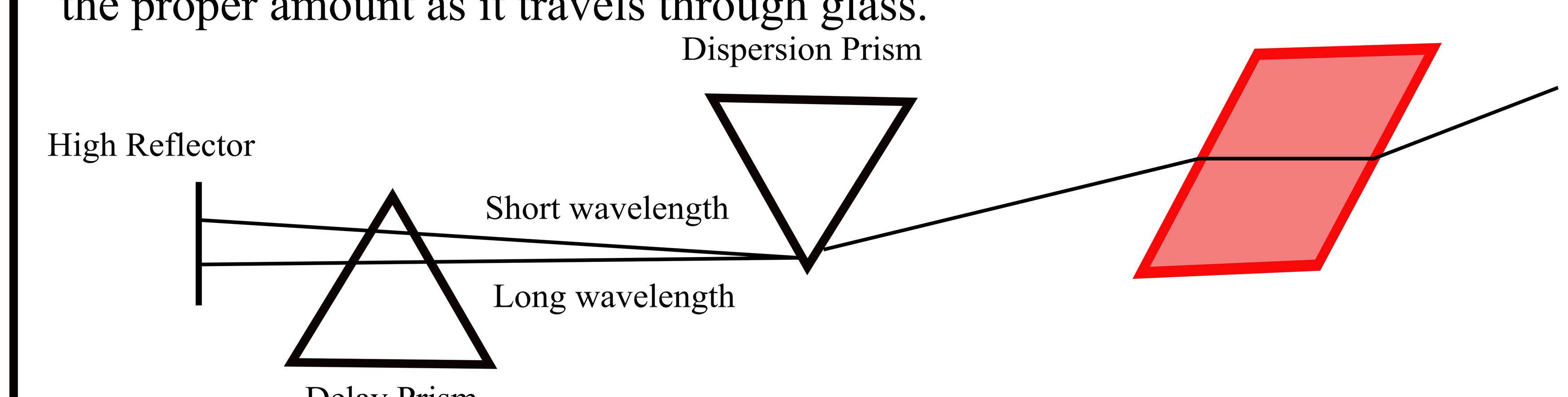

Fig. 8[1]: Visualization of pulsating prism configuration.

Acknowledgments

This work was supported by Saint John's University Physics Department. In addition, I would like to thank my advisor Dean Langley for all his time and effort throughout this project.

References

1: Figure by Max Hansen
2. Pedrotti, Frank L., et al. Introduction to Optics: Frank L. Pedrotti, Leno S. Pedrotti, Leno M. Pedrotti. Pearson Prentice Hall, 2007.