P443/P444 - Open Lab Experiment

Nd-YAG Laser : Experimental Implementation

Submitted By

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I. Introduction

LASER stands for Light Amplification by Stimulated Emission of Radiation. It is a source of highly directional and intense light, that is monochromatic and coherent. Lasers find a wide range of applications in the fields of research, medicine, communication, military etc.
In the previous part of this report, submitted before mid-semester examinations, the theory of lasing was discussed in detail. In this report, I will attempt to give details about the experimental setup and the experiments we performed.

II. Experimental Set-Up

The experimental set-up consists of several optical components, along with an optical rail, to position the components in place. The various modules are as follows :

2.1 Diode Laser (Module A)

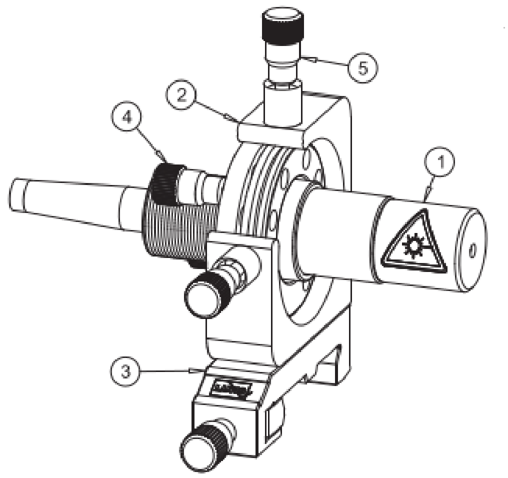

Fig 1. Diode Laser (Module A)

This module consists of a Laser diode of 808nm (1). It has a maximum power of 500mW at 20^oC. The laser is temperature controlled and acts as a source. It is fixed on an adjustment holder (2) which is attached to the carrier (3) which is used to put the laser on the optical rail. The temperature of the laser can be varied from 15^oC to 35^oC. (4) and (5) are precision fine pitch screws are used for micro-adjustments to align the optical axis of the laser with the mechanical axis of the set-up.

2.2 Collimator (Module B)

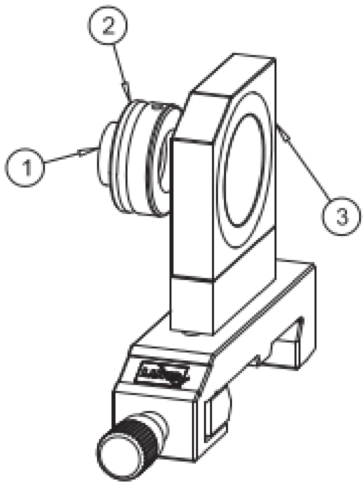

Fig 2. Collimator (Module B)

This module consists of a collimator to collimate the divergent beam from the diode laser. The collimator (1) itself consists of three lens system which has a short focal length of around 8mm and a large aperture. It is mounted on a holder (2). The holder is placed on a mounting stand (3) to attach the collimator to the optical rail.

2.3 Focussing Unit (Module C)

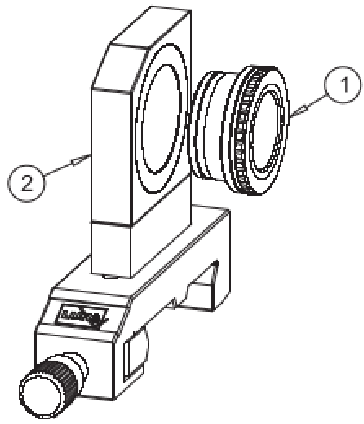

Fig 3. Focussing Unit (Module C)

This module consists of a focussing unit used to focus the collimated beam on the crystal (which is mounted on Module D). The focussing lens (1) has a focal length of about 60mm. It is mounted on a 25mm click holder (2). The holder itself is placed on a mounting stand to attach the focussing unit to the optical rail.

2.4 Adjustment Holder with the NdYAG crystal (Module D)

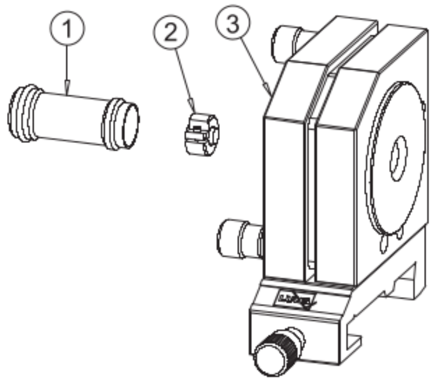

Fig 4. Adjustment Holder with NdYAG (Module D)

This module consists of an adjustment holder (3), an exchangeable mount (1) and a plane-parallel NdYAG crystal (2). The NdYAG crystal rod is polished on one end to form a plane-parallel mirror. This coating is highly reflective for 1064nm and forms the left resonator mirror. The mirrored side is positioned to face the focussing unit, and subsequently the 808nm emission from the diode laser. The mirroring is such that it is transparent to the incoming 808nm emission. The other end of the rod is coated with an anti-reflection layer for 1064nm to keep the resonator losses low. The backside of the crystal is also coated with a high reflective layer for 532nm to redirect the green light to the output of the resonator in the case of Second Harmonic Generation. The NdYag crystal (2) is placed in the exchangeable mount and mounted on the adjustment holder. The holder is fixed on a mounting stand to fix the entire system on the optical rail. The fine pitch screws on the adjustment holder help in positioning the resonator mirror such that that the common optical axis is aligned perpendicular to the mirrors.

2.5 Adjustment Holder & Resonator Mirror (Module E)

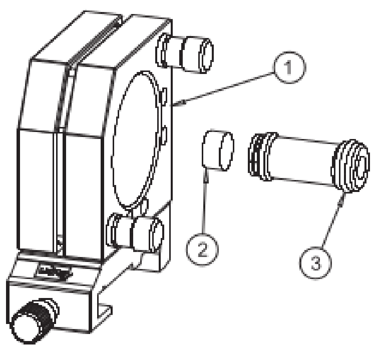

Fig 5. Adjustment Holder with Resonator Mirror (Module E)

This module is very similar to Module D and contains the second resonator mirror (2). The mirror is placed in the fixture (3) which, in turn, can be screwed into the holder (1). The mirror is highly reflective, has a diameter of approximately 0.5inches, and radius of curvature around 100mm.

2.6 Filter Plate Holder (Module F)

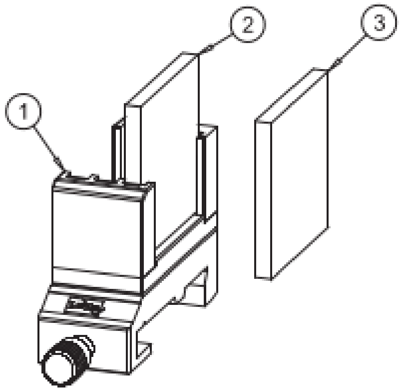

Fig 6. Filter Plate Holder (Module F)

This module consists of a filter plate holder (1), along with two different filters, RG1000 and BG39. RG1000 filter allows only the 1064nm wavelength to pass, and the BG39 filter only allows the 532nm wavelength to pass.

2.7 Photodetector (Module G)

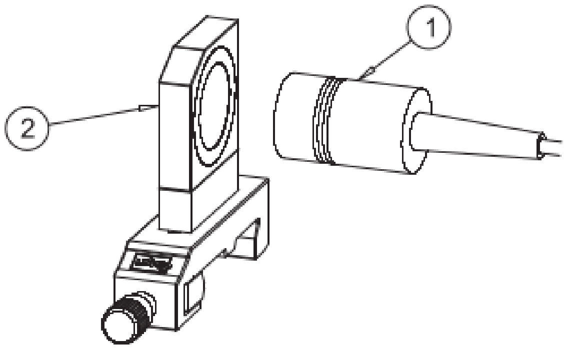

Fig 7. Photo-detector (Module G)

This module contains a Silicon-PIN photodetector (1) with a holder (2). The detector is connected to a signal conditioner box, which allows the photodetector signal to be observed in an oscilloscope.

2.8 Photodetector Signal Conditioner Box

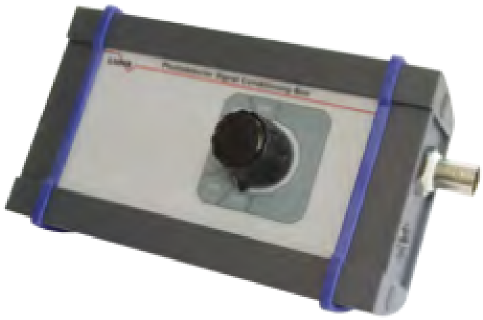

Fig 8. Signal Conditioner Box

The signal conditioner box is attached to the photodetector and allows the signal from the same to be fed into an oscilloscope. It achieves this by converting the photodetector current, that is the number of incident photons into voltage. The apparatus is driven by a 9V battery. The output impedance can be adjusted from 50Ω to 100kΩ. The "OFF" position provides very high sensitivity via a 1MΩ shunt. For fast signals, the lower shunt resistors are used.

2.9 Digital Laser and Peltier's Element Controller

Fig 9. Peltier's Element Controller

This module is a fully digital device which can control both the injection current and temperature of the diode laser. A multi-pin connector is used to connect the laser diode to the device.
The injection current can go up to 1000mA, in steps of 10mA. The temperature can be varied between 15^oC and 35^oC.

III. Experiments

We perform several experiments to ascertain the properties of the NdYAg laser.

3.1 Absorption Spectrum of the Diode Laser

In this experiment we determine the dependence of the wavelength of the laser diode beam on the temperature of the diode and the injection current. From the energy level diagram of Neodymium ions, we see that it has four absorption transitions at wavelengths : i.) 804.4nm ii.) 808.4nm iii.) 812.9nm and iv.) 817.3nm. The absorption peaks are observed in the range of 0^oC and 60^oC, but in our setup we only observe one peak as the temperature can be varied between 15^oC and 35^oC only.

3.1.1 Set-Up

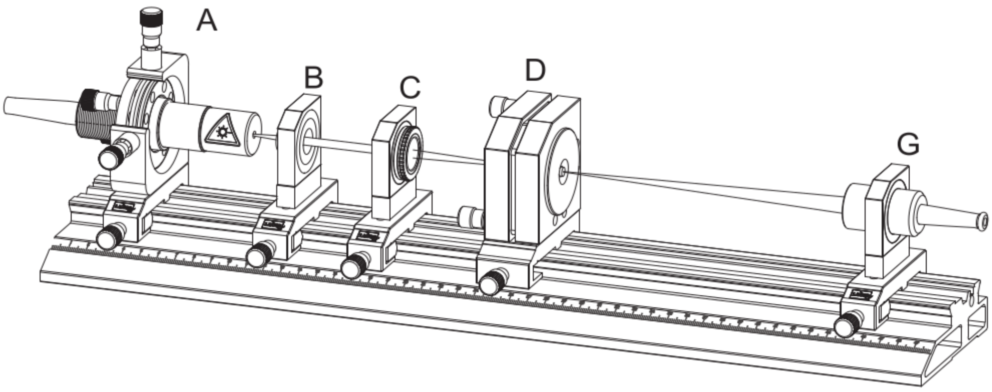

Fig 10. Absorption Spectrum Set-Up

In this setup, we only need Modules A through D, and the photodetector. As we are not observing any properties of the lasing action of the NdYAG, we do not need to form the optical cavity. Thus, we do not have the second resonator mirror in the setup.

3.1.2 Observation & Results

To take measurements, we fixed one value of the injection current and varied the temperature of the diode laser. The data obtained for 200mA and 300mA is plotted separately from the others as the data points for the same were recorded with a different impedance value than the others.

The peak that we observe in the figure is the peak for the 808.4nm wavelength.

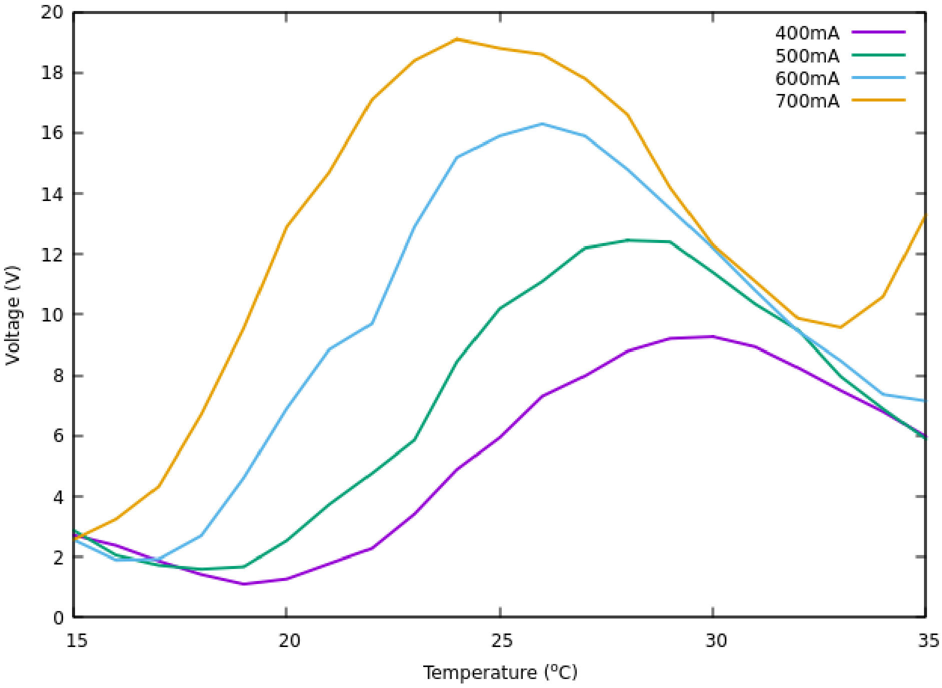

Fig 11. Absorption Spectrum (400mA to 700mA)

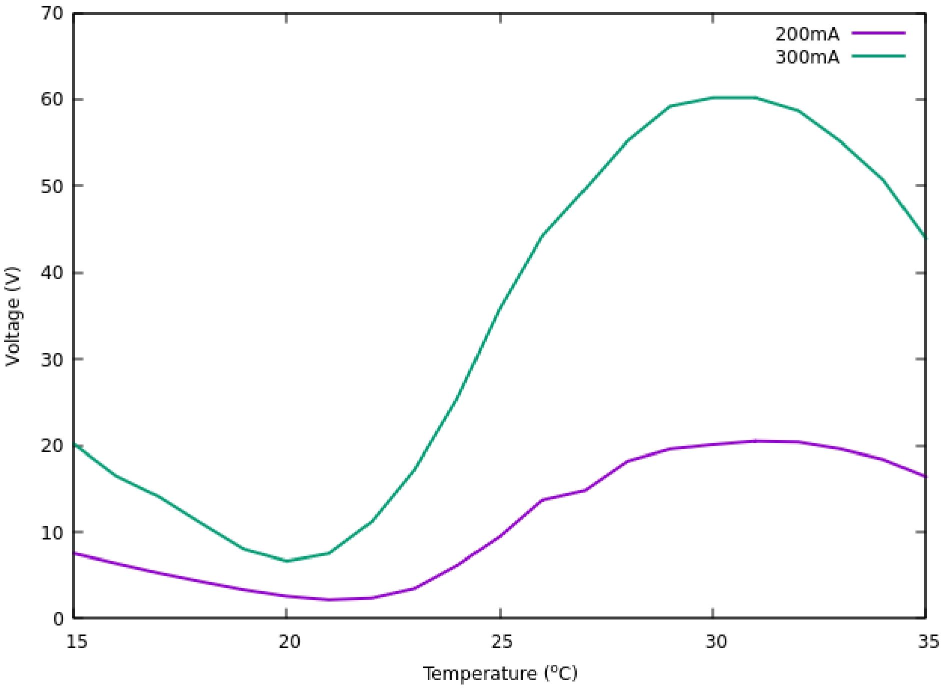

Fig 12. Absorption Spectrum (200mA & 300mA)

We observe that as the position of the peak gets shifted towards the lower temperatures with increase in injection current. The output of the diode laser is maximum for 700mA current at a temperature of about 23^oC. The voltage values of 200mA and 300mA were almost negligible when measured with the impedance value as the other data points, thus a lower impedance value was used to measure their variation.

3.1.3 Wavelength and Temperature Dependence

From the above results we can clearly observe that the absorption is maximum for a certain value of temperature. We wish to operate our diode such that the wavelength remains constant and the absorption is maximum. We obtain a linear relationship between injection current and temperature, from the data of the previous experiment.

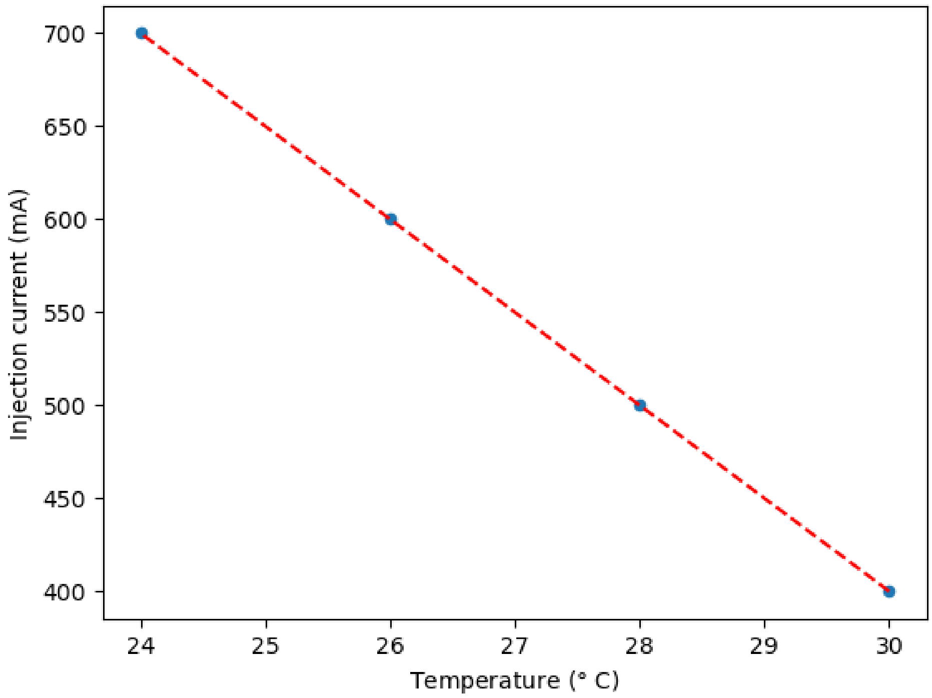

Fig 13. Injection Current vs. Temperature

The wavelength remains constant, because with the increase in wavelength due to increase in temperature is compensated by the corresponding decrease in wavelength due to decrease in current. The wavelength is 808.4nm and it is used for all the other experiments.

3.2 Power of the Laser Diode

In this experiment, we determine the dependence of the power output of the diode laser on the temperature of the diode and the injection current.

3.2.1 Set-Up

The setup for this experiment is same as the setup for the previous experiment with the addition of RG1000 filter (Module F) after Module D, as given in Fig 10. Also here, instead of the photodetector (Module G), we have an optical power meter to measure the output power of the diode laser. We do not need any more modules to form the optical cavity as we are attempting to observe the characteristics of the diode laser itself, and not the NdYAG laser.

3.2.2 Observation & Results

First we observe the variation of output power with changing injection current at some fixed temperature. We repeat the process for two values of temperature : 20^oC and 28^oC.

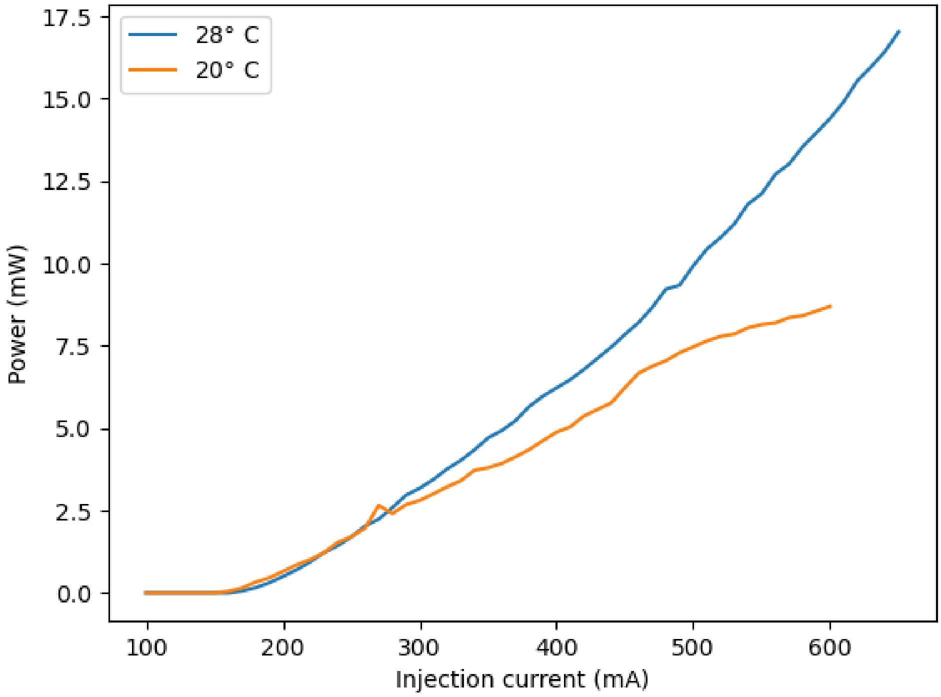

Fig 14. Laser diode power as a function of injection current at different temperatures

Secondly, we observed the variation of output power with temperature for fixed values of injection current, above the threshold value.

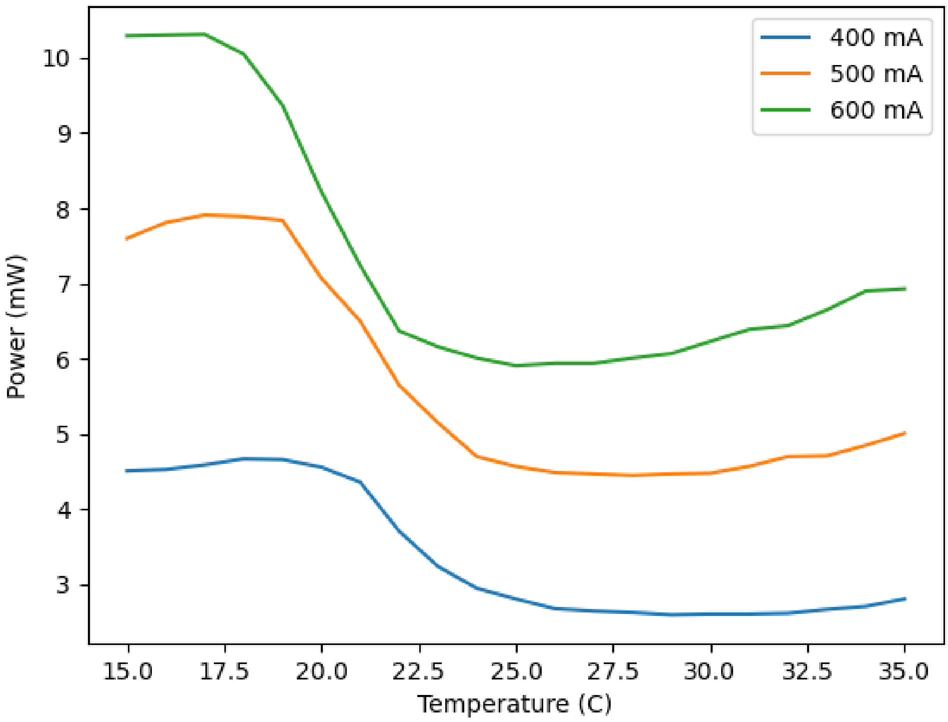

Fig 15. Laser power diode as a function of temperature at different injection currents

From the first plot (Fig 14), we observe that the output power varies roughly linearly with injection current. With the increase in injection current, the power increases. We also observe that the diode laser requires some threshold injection current to work. For out setup, the threshold current is around $150mA \pm 10mA$.
If the injection current is below the threshold value, the power output is almost negligible.

From the second figure we observe that the output power is maximum at the lower temperatures, and starts falling after $20 - 21^oC$. It matches our expectation from the previous plots of voltage vs. temperature for different injection currents in the absorption spectrum experiment.
We operate the laser diode at around 20^oC with 600mA injection current for the best results.

3.3 Lifetime of ^{4}F$_{3/2}$ Level

From our discussion of the theory of lasing in NdYAG in the previous report, we know that the metastable state of the NdYAG crystal is the $^4F_{3/2}$ state which emits the 1064nm wavelength radiation. In this part of the experiment we want to find the lifetime of this metastable state.
The lifetime of a state is defined as the time taken by the intensity of the transient light to reduce to $1/e$ of the original intensity. The lifetime of a metastable state is expected to be longer than the lifetime of other states. For $^4F_{3/2}$ we expect the lifetime to be around $250\mu s$.
The lifetime can be measured directly from the oscilloscope output.

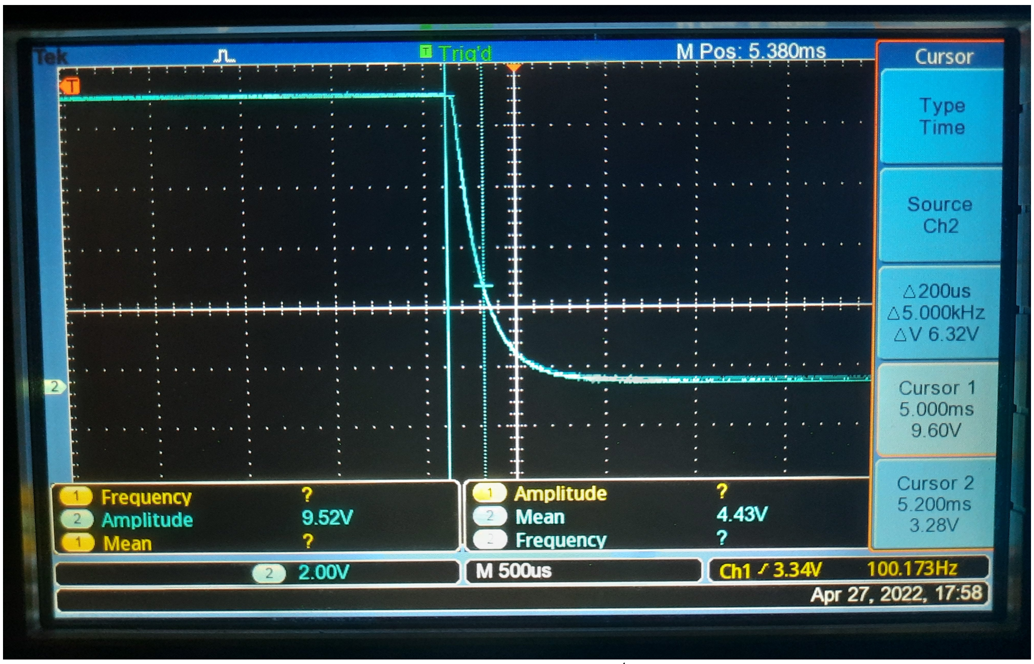

Fig 16. Lifetime of $^4F_{3/2}$

We observe the lifetime to be around $200\mu s$. The error in measurement could be due to the response time of the detector.

3.4 Spiking

To measure the phenomenon of spiking, we first need to setup the NdYAG laser.

3.4.1 Theory

When the laser diode is turned on, there is huge deviation from the steady state. Until the population inversion is reached, there are no photons in the resonator. Even after population inversion is reached, it takes a finite amount of time to reach the steady state. During this time, the population inversion keeps on increasing, crossing the threshold, and consequently, the photon density in the resonator also keeps increasing. When the inversion decreases slightly, the oscillation stops. This process keeps on repeating until steady state is reached.

The initial spike is the highest, and the overshoot of population inversion keeps on reducing with subsequent spikes. The first spike can have power values 1000 times greater than the steady state power. Thus, spiking can be really dangerous as it can lead to the destruction of optical surfaces and materials. The optical component can get destroyed as soon as the laser is turned on due to the extremely high power build-up.

This behavior also suggests that the NdYAG crystal can store power.

3.4.2 Set-Up

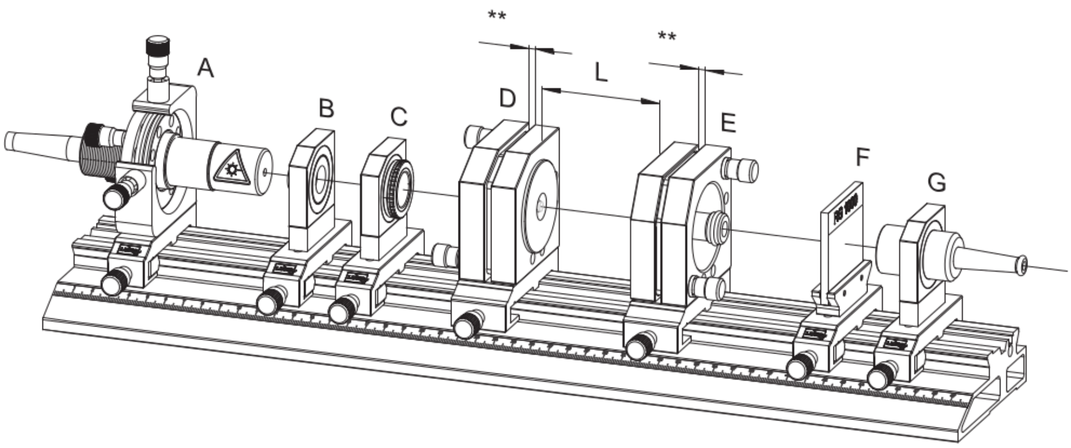

Fig 17. Setup for NdYAG Laser

In this setup, we need all the modules discussed, and we need to carefully align the optical axis of the experiment. Once we obtain lasing action, we would observe sparking between the mirrors in the resonator cavity (between modules D and E). It implies that the mirrors are perfectly aligned. We would also observe the 1064nm after the filter on a special IR-card.

3.4.3 Demonstration of Spiking

We can directly observe the phenomenon of spiking by looking at the oscilloscope output. We require to turn on the modulator of the laser diode and set the impedance to $50k\Omega$ value.

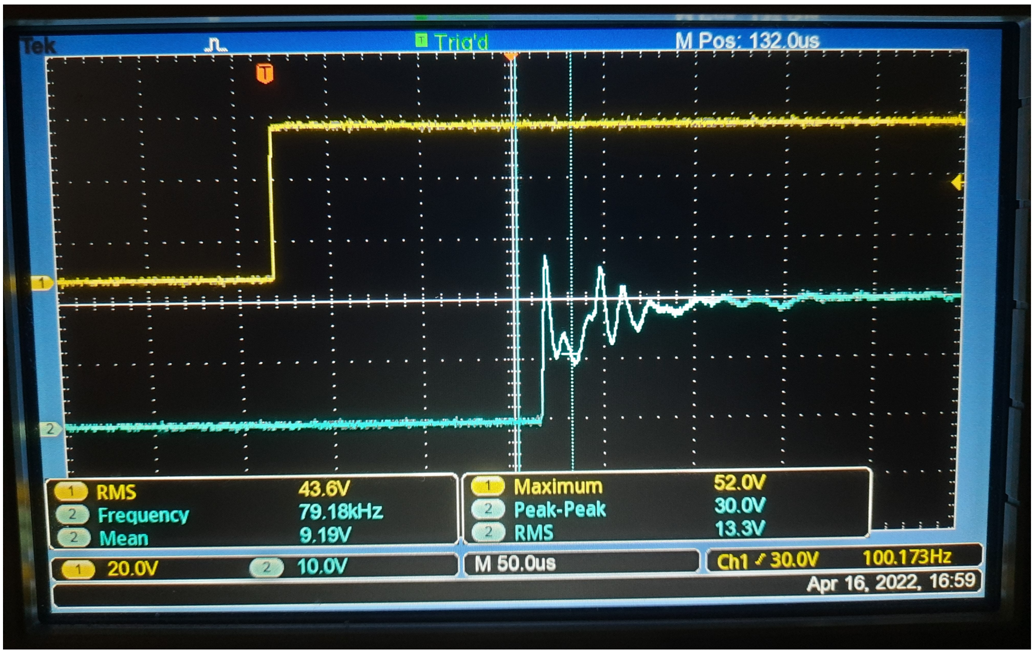

Fig 18. Spiking

We also observe that there is a time lag between turning on of the diode laser and the first peak of spiking. We varied the injection current and observed the change in this time lag at 20^oC temperature.

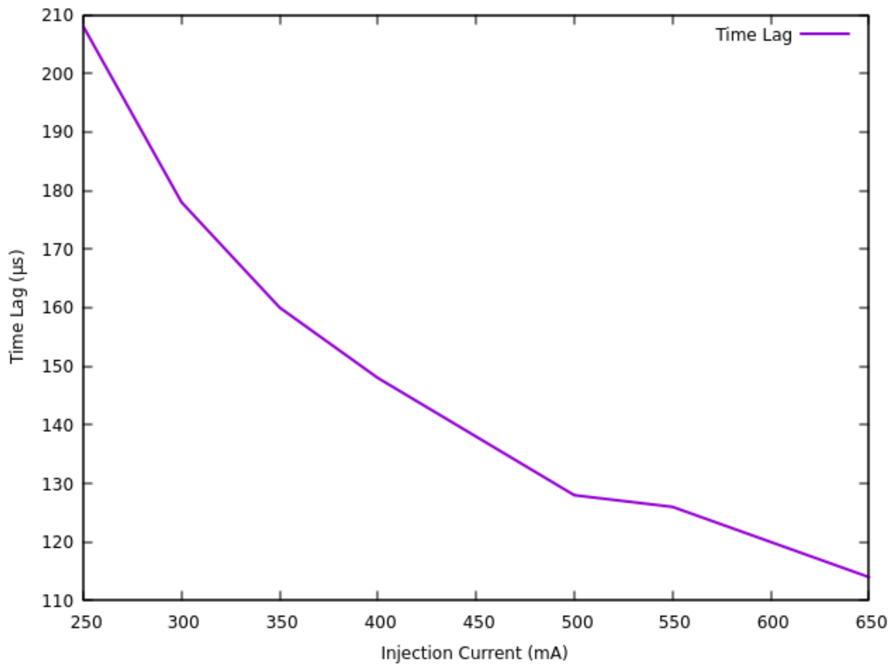

Fig 19. Time Lag vs Injection Current

We observe that the time lag decreases with an increase in injection current.

3.5 Second Harmonic Generation

Second Harmonic Generation is a nonlinear process, and to observe the same, we need to include a non-linear optical element in the setup. In our experiment, a KTP (Potassium Titanyl Phosphate) crystal acts as the nonlinear element and is inserted inside the optical cavity.

3.5.1 Set-Up

In this setup, we need an additional module to hold the KTP crystal, i.e., Module K.

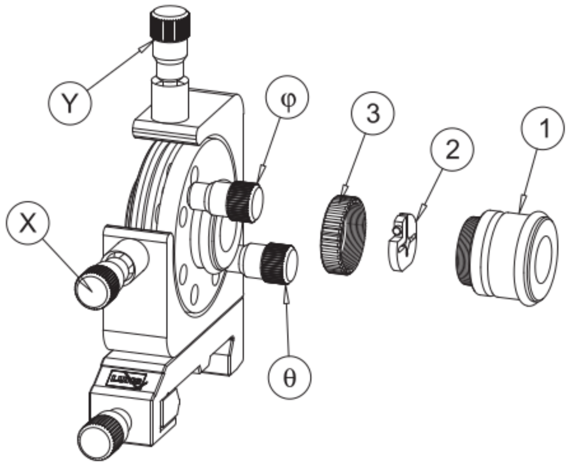

Fig 20. Frequency Doubler (Module K)

The KTP crystal generates 532nm : the second harmonic of fundamental 1064nm wave. The crystal in (2) is inserted into a holder (1) and screwed in position using (3). The fine and coarse adjustment screws are used to align the crystal to the optical axis.

The entire Module K is inserted inside the optical cavity of the setup.

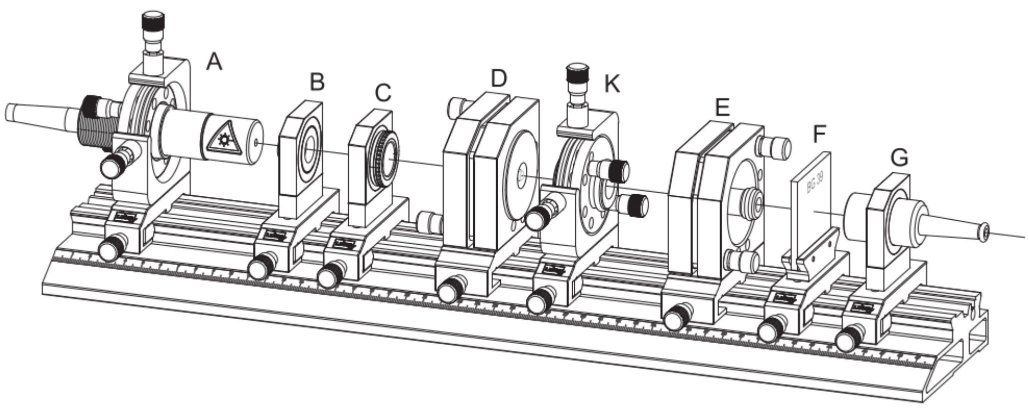

Fig 21. Second Harmonic Generation Setup

Also, instead of RG1000 filter, we now use BG39 filter to allow only the green light (532nm) to pass through.

3.5.2 Observation & Results

We first compared the power of second harmonic generation to the power of the fundamental beam at 20^oC (each power is a function of injection current).

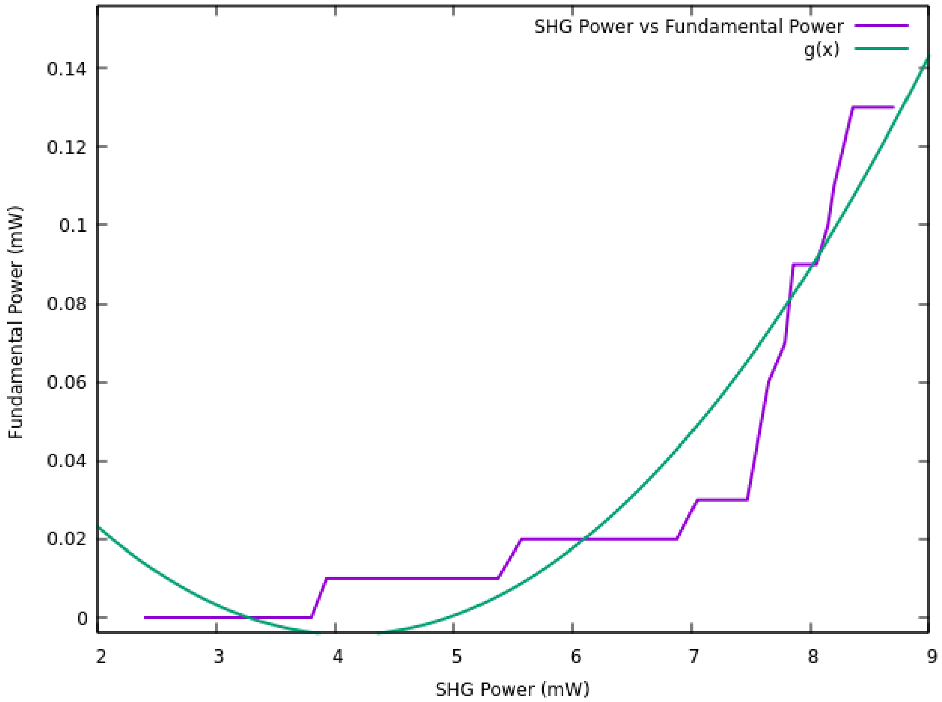

Fig 22. SHG Power vs Fundamental Power

We then observed the variation of the SHG power for different temperatures at some fixed injection current value.

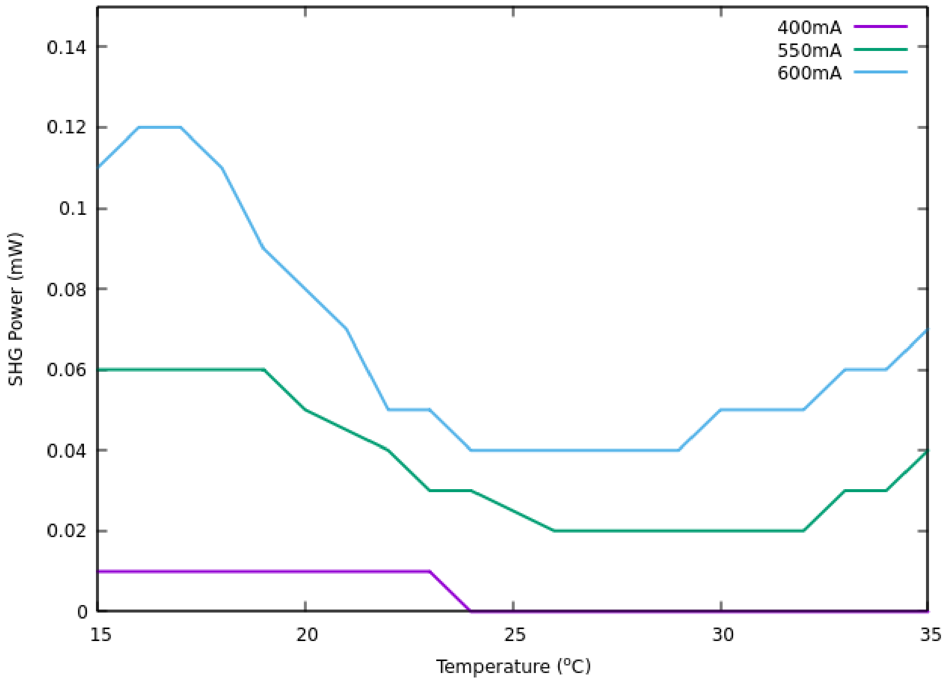

Fig 23. SHG Power for different temperature

From the first graph, we observe that the SHG power varies with the fundamental power in a way which looks like it could be quadratic fit, but is far from perfect. g(x) is the best fit quadratic fit found.

From the second graph we observe that the the output power peaks at lower temperatures, and is significantly higher from higher injection current. It roughly follows the pattern of the power variation of the laser diode with temperature.

3.6 Q-Switching

Q-switching is a technique by which a laser can be made to produce pulsed output beam. We discussed the theory of Q-switching in our previous report.

We tried to implement passive q-switching in our experimental setup using CrYAG as our crystal. But we were unable to align the crystal properly with the optical axis of the setup. The best output we could obtain is as follows :

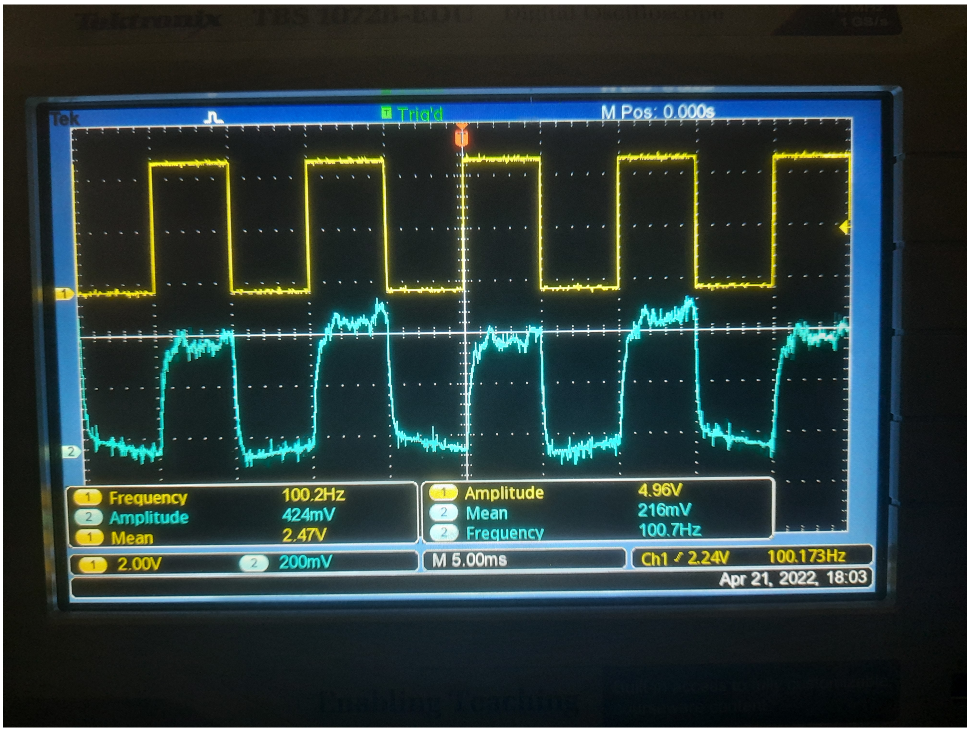

Fig 24. Attempt at Q-Switching

The output is far from the expected q-switching behaviour. We could not align the crystal any further to obtain any better result.

IV. Results and Conclusions

While we were performing the experiment, we faced prolonged issues in the alignment procedure. We were able to obtain alignment and lasing action after almost a period of 4.5weeks. This severely restricted the amount of time we had available to perform the experiments.

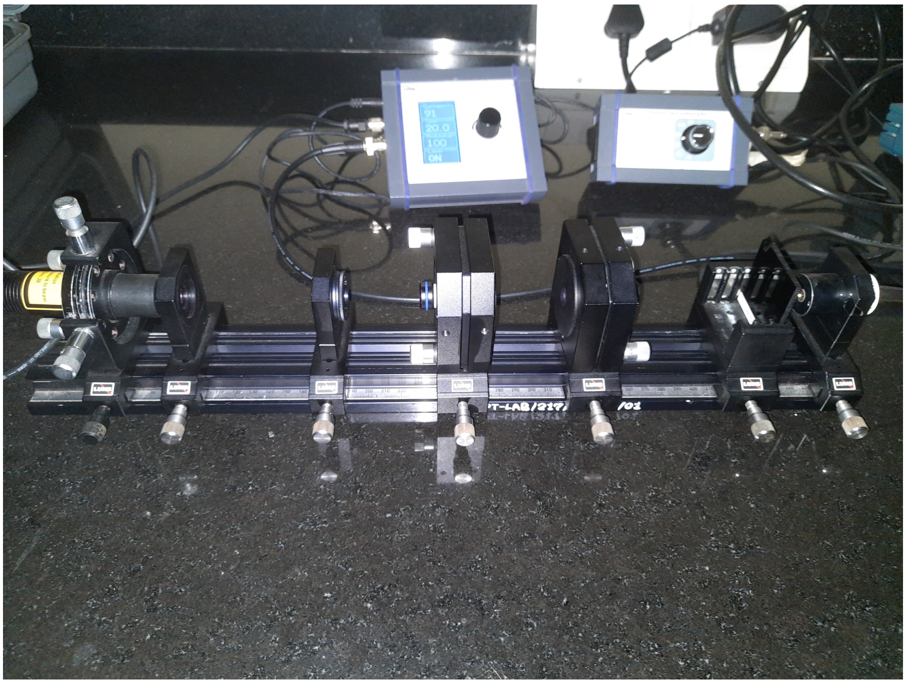

Fig 25. Laboratory Setup for NdYAG Laser

In conclusion, we

i.) successfully aligned the optical axis and obtained lasing action.

ii.) observed the absorption spectrum of the NdYAG crystal and verified the diode characteristics.

iii.) obtained the threshold current of the diode to be around $150mA \pm 10mA$.

iv.) measured the lifetime of the $^4F_{3/2}$ state to be around $200\mu s$.

v.) observed the phenomenon of spiking. We also found a relation between injection current and time lag of the first spike in spiking.

vi.) obtained Second Harmonic Generation and measured its output power as a function of temperature and injection current.

vii.) were unable to obtain the phenomenon of q-switching due to alignment issues in the setup and the inevitable lack of time.