Experimental Realization of Nd-YAG Laser

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The Nd-YAG (Nd^{3+} ions doped in $Y_3Al_5O_{12}$) laser is a commonly used lasing system that emits laser radiation in the wavelength $\lambda = 1064$ nm. The fundamental components of any lasing system consists of an active medium, pump source (typically a diode laser is used) and an optical cavity resonator. In this experiment, we proceed to measure the absorption spectra of Nd-YAG crystal to determine the dependence of diode laser wavelength on its temperature. In addition, we also perform measurements to determine the lifetime of the $^4F_{3/2}$ metastable state. For subsequent plans, we plan on investigating nonlinear phenomena such as second harmonic generation, in addition to TEM modes along with the experimental implementation of Q-switching using a passive Q-switch i.e. Cr-YAG crystal.

INTRODUCTION

LASER stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. It is a source of highly directional and intense light, with the emitted radiation being monochromatic and coherent in nature.

In our discussion, we shall deal with a particular type of laser called Neodymium Yttrium Aluminium Garnet (Nd-YAG) laser. This laser has various medical and scientific applications especially in spectroscopy and surgery. Here, we shall discuss the working principle of a general laser and Nd-YAG laser in particular. Afterwards, the experiment along with the relevant setup is described and results inferred.

EXPERIMENTAL SETUP

Here, we proceed to describe the setup of our experiment consisting of various optical elements, an optical rail for their subsequent placement.

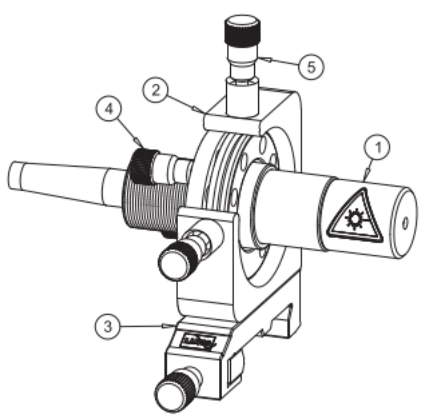

FIG. 1. Diode Laser (Module A)

Diode Laser (Module A): This module contains a diode laser with an emission spectrum containing 808 nm (1) light. The corresponding power is maximum at $20°$ C with a value of 500 mW. It is controlled via a *Peltier's element* which controls the injection current and temperature of the laser. As shown in fig. 1, it is attached to the adjustment holder (2) which is further attached to the carrier (3). This helps us fix the laser onto the optical rail.

In our setup, the temperature can be varied between $15°$ C and $35°$ C. The fine precision pitch screws (4 & 5) are used to micro-adjustments in order to align the optical axis of the diode laser with the overall mechanical axis of the optic rail.

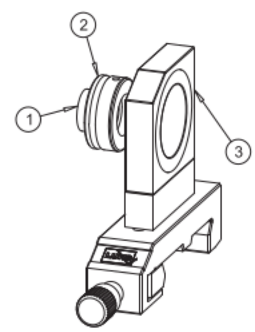

FIG. 2. Collimator (Module B)

Collimator (Module B): This module contains a collimator unit whose main task is to supply a parallel beam of light from the original divergent beam originating from the diode laser. It (1) consists of a three-lens system housed within a body with a large aperture and a focal length of 8 mm. It is mounted onto the holder (2) as shown in fig. 2. The holder is then fixed onto the optic rail of the setup.

Focussing Unit (Module C): Shown in fig. 3, this module consists of a focussing unit needed to focus the collimated beam of light originating from the

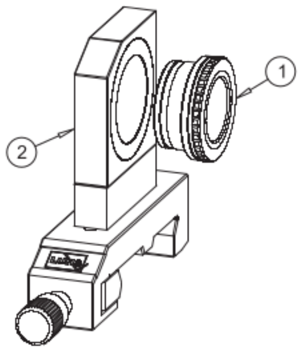

FIG. 3. Focussing Unit (Module C)

collimator onto the crystal (which is to be mounted onto module D). The lens (1) has a focal length of 60 mm and is mounted onto a 25 mm click holder (2). This is further placed and fixed on the optic rail of the setup.

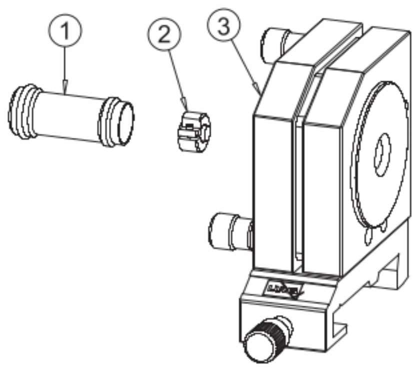

FIG. 4. Adjustment Holder (Module D)

Adjustment Holder (Module D): Shown in fig. 4, this module contains an adjustment holder (3) for housing the Nd:YAG crystal (2) onto an exchangeable mount (1). The crystal itself is polished on one of its ends to form a plane-parallel mirror. This polished coating is highly reflective for the emergent wavelength of light (1064 nm) and hence forms the left resonator of the entire optical cavity (to be mounted subsequently). This polished end of the crystal is placed to face the focussing unit. This mirrored coating is such that it is transparent to the 808 nm emission from the diode laser. The other end of the crystal is coated with an anti-reflection layer for 1064 nm light in order to keep the losses in the resonator cavity low. This end is also coated with a highly reflective layer for 532 nm light, in order to allow the outward propagation of corresponding green light out of the resonator cavity for the second harmonic generation experiment.

The crystal is placed in the exchange mount, which is mounted onto the corresponding adjustment holder. This is then fixed onto the optic rail. The fine adjustment screws help in aligning the resonator mirror in a way that the common optical axis of positioned perpendicularly to the mirrors.

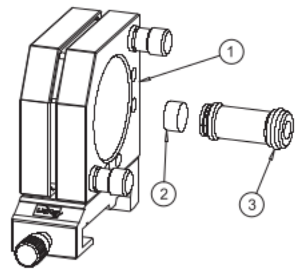

FIG. 5. Adjustment Holder with resonator mirror (Module E)

Holder & Resonator Mirror (Module E): Similar to module D, this contains a second resonator mirror (2) to form the overall cavity resonator. As shown in fig. 5, the mirror is placed inside a structure (3) which is then screwed onto the holder (1). This mirror has a spherical structure and is highly reflective, with a radius of curvature of roughly 100 mm.

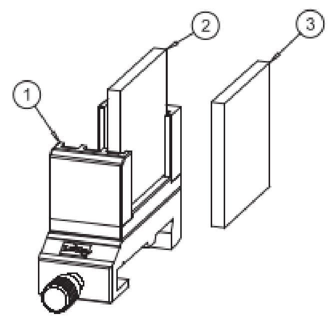

FIG. 6. Filter plate holder (Module F)

Filter plate holder (Module F): In this module, two different filters depending on the experiment being performed i.e. RG1000 and BG39. The former filters out 808 nm light which is sent as input to the whole setup. The latter filter only allows light of 532 nm wavelength to pass through. The corresponding module is shown in fig. 6.

Photodetector (Module G): This module consists of a silicon-PIN photodetector (1) with a holder (2). This detector is then connected to a signal conditioner box, which allows the corresponding photodetector signal to be observed on an oscilloscope. The corresponding module is shown in fig. 7.

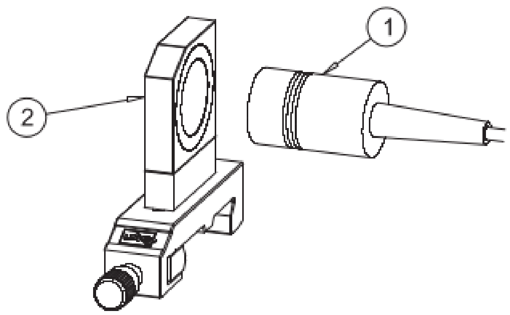

FIG. 7. Photodetector (Module G)

FIG. 8. Signal conditioner box

Signal Conditioner Box: This component allows for the signal from the photodetector to be fed onto the oscilloscope. This is achieved by converting the measured photodetector current (corresponds to the number of photons incident on the photodetector) to voltage. This apparatus is driven via a 9V battery. The impedance can be tuned from 50 Ω to 100 kΩ. The "OFF" position gives a high sensitivity using a 1 MΩ shunt resistance. The fast signals, the lower shunt resistance value is used. The corresponding unit is depicted in fig. 8.

FIG. 9. Peltier's element controller

Peltier's Element Controller: This component is a completely digital device which allows the user to control the supplied injection current and temperature of the diode laser. The laser diode and the device is connected via a multi-pin connector. The injection current can be adjusted to a maximum value of 1000 mA. The range of temperature control is between $15°$ C and $35°$ C. The corresponding unit is depicted in fig. 9.

EXPERIMENTS PERFORMED

During our hands-on experimental demonstration of the Nd:YAG laser, we performed several experiments. The details for the same are subsequently provided.

Absorption Spectrum of Diode Laser

During this experiment, the objective is to determine the wavelength of the diode laser beam as a function of diode temperature and supplied injection current. From the energy level diagram of Nd^{3+} ions (see fig. 10), we see that there are four absorptions peaks at wavelengths 804.4 nm, 808.4 nm, 812.9 nm and 817.3 nm. All of these peaks are observed between a temperature range of $0°$ C and $60°$ C. However, our setup only allows temperature tuning in the range $15°$ C to $35°$ C.

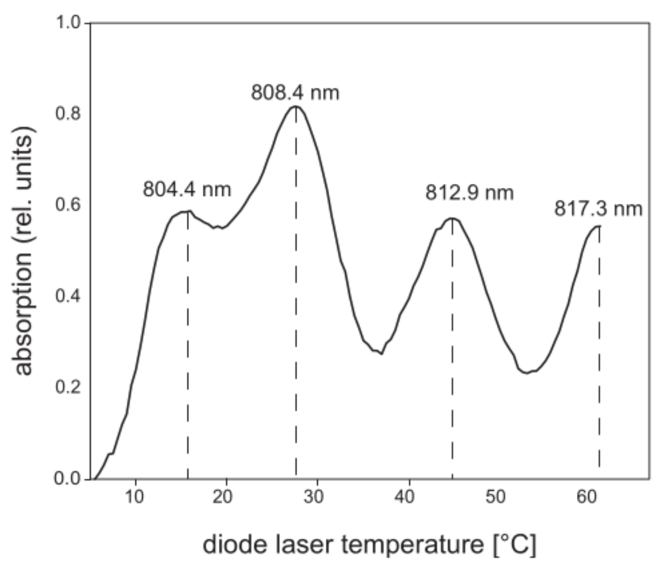

FIG. 10. Energy level diagram of Nd^{3+} ions.

Setup: For measuring the absorption spectra, we only need modules A through D, along with the photodetector. Note that we do not require an optical cavity for this case since we not observing any property related to the lasing action of the Nd:YAG crystal.

Results: In order to measure the spectra, we fixed the value of injection current and slowly varied

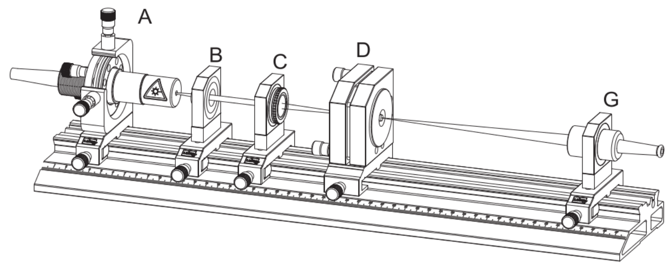

FIG. 11. Experimental setup for observing absorption spectra of Nd^{3+}.

the diode laser temperature. We measured the corresponding voltage vs temperature for injection current values 400 mA, 500 mA, 600 mA and 700 mA as shown in fig. 12. We also measured for injection currents 200 mA and 300 mA (see fig. 13) but with lesser impedance value for greater sensitivity. The observed peak corresponds to a wavelength of 808.4 nm.

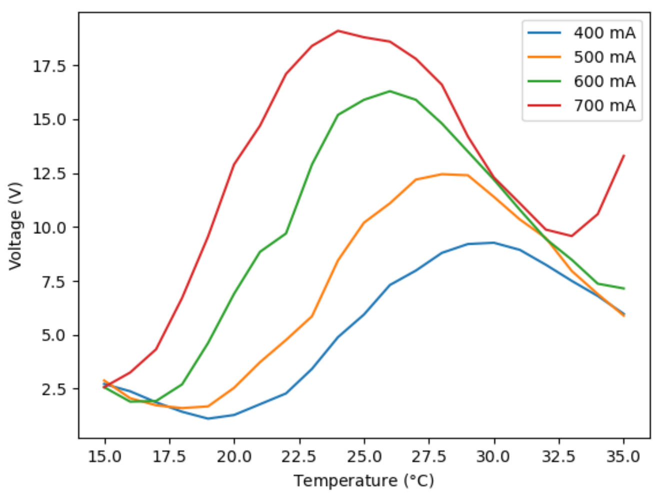

FIG. 12. Absorption spectra seen for injection current values 400 mA - 700 mA.

From fig. 12, we see that the position of the absorption peak shifts towards lower temperatures with increasing injection current. As seen from the plot, the output of the diode laser at 700 mA injection current is maximum at around 23° C.

Wavelength and temperature dependence

As seen from fig. 12 in our previous experiment, the absorption peaks at a certain value of diode temperature. The goal is to operature the diode laser such that this absorption peak is maintained and

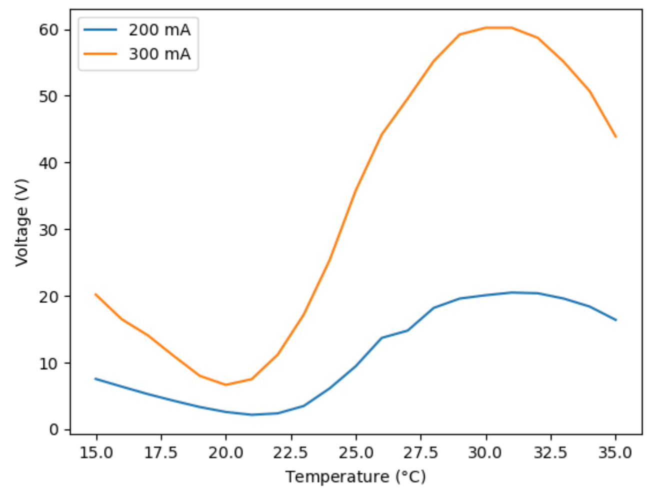

FIG. 13. Absorption spectra seen for injection current values 200 mA and 300 mA.

hence the wavelength remains constant (at a value of 808.4 nm). Plotting the corresponding variation of the injection current with temperature using data obtained from the absorption spectra, we observe a linear relation as shown in fig. 14.

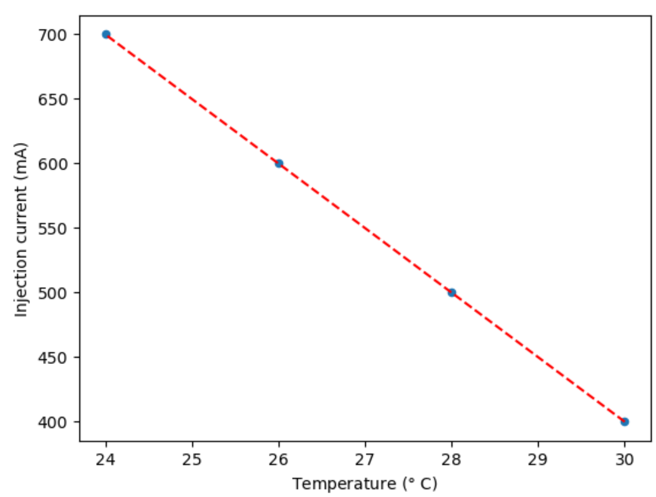

FIG. 14. Plot of injection current as a function of temperature at a constant wavelength of 808.4 nm.

This constant wavelength of 808.4 nm is used throughout all our experiments. The wavelength here remains constant from the simple concept of proportionality where with an increase in wavelength will be seen due to increase in temperature but at the same time a decrease is seen with decrease in injection current.

Power of Laser Diode

The objective here is to determine the output power of the diode laser as a function of diode temperature and injection current.

Setup: The setup remains the same as fig. 11 except that here, we also add an RG1000 filter after module D. In addition, since we are interested in determining the output power, a photodetector does not allow such measurement and thus we employ a optical power meter for the same. Once again, since we are interested to determining these parameters for the diode laser and not the Nd:YAG laser, setup of the cavity resonator is not done.

Results: For a fixed temperature, we first measure and observe the variation of output power as a function of injection current. This is done at two temperature values i.e. $20°$ C and $28°$ C.

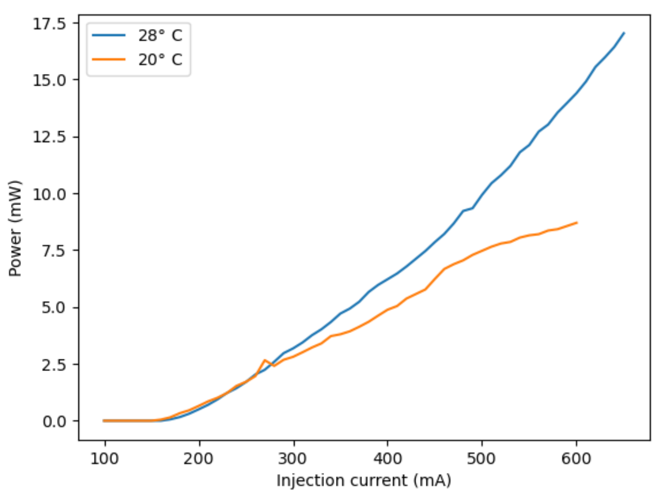

FIG. 15. Output power of laser diode as a function of injection current at various temperatures.

Subsequently, we also measure and observe the output power variation as a function of temperature at fixed values of supplied injection currents.

From the above plots, let us make certain inferences. From fig. 15, the output power varies approximately in a linear fashion with injection current. It is also observed that this linear increase in power is seen only after the injection current crosses a threshold value, which from the data obtained (and hence in fig. 15)

ACKNOWLEDGEMENT

This is an acknowledgement.

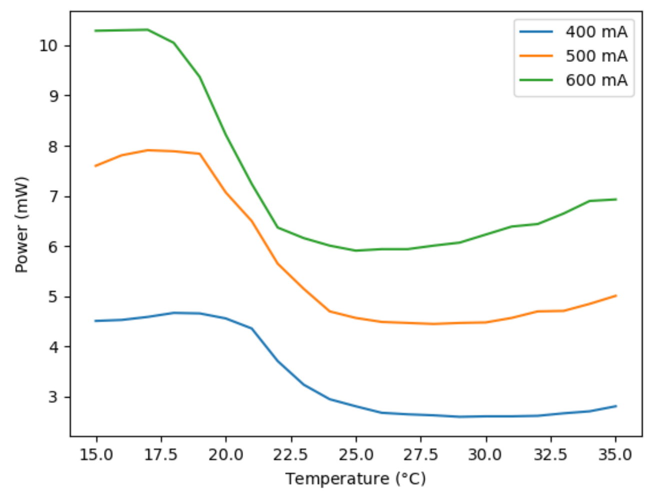

FIG. 16. Output power of laser diode as a function of temperature at various injection current values.

[1] Svelto, O. and Hanna, D. C. (1998). *Principles of lasers*, volume 4. Springer.

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