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Photopumped laser diode continuous wave for optical gain determination of $Nd:YVO_4$ and Nd:YAG crystal medium

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Abstract

Photopumped based on laser diode (LD) has designed by employing optical instruments which consist of laser source, optical lens and mirrors as resonator. This setup is aimed to determine of luminescence intensity of laser gain medium based on Nd:YAG and $Nd:YVO_4$ crystals. Laser diode at 805 nm with continuous wave (CW) mode was used as pumping light source with the maximum output power 1 W. The 1064 nm wavelength laser can be obtained through a LD side pumped to laser gain medium, Nd^{3+} doped YAG and YVO_4 crystals respectively. Laser gain medium is placed between intra cavity resonator and generates the laser power reflected in power output (mW or Watt). The luminescence spectra of both crystals medium is utilized to obtain optical gain in dB (decibels). The obtained maximum gain of $Nd:YVO_4$ and Nd:YAG mediums are 24.278 dB and 4.4 respectively, for absorbed pump power at 900 mW. The $Nd:YVO_4$ crystal is able to produce a higher laser output intensity compared with Nd:YAG crystal. The arrangement of high reflectance or transmittance (HR/HT) mirror and lens as optical resonators are very important because they are related to the high power of laser output.

1. Introduction

The optical pumping system is important to produce high-power for solid state lasers. Some of the current pumping methods are based on a pulsed and continuous wave (CW). Recently, Li et al. [1] obtained 3.62 W laser output power through $Nd:YVO_4$ crystal as laser medium with 27.5 W and CW mode pumping source. Cui et al. [2] reported that laser diode (LD) with CW mode was used as pumping source on $Nd:GdVO_4$ crystal, to obtain output power of 82 W. Besides the resonator, the utilization of optical gain medium and optical pumping system are necessary to produce high output power of lasing. The function of the pumping system is excitation of the active ion from fundamental energy level to the higher energy level so that the emission or fluorescence can be achieved [3,4]. The active ions from the laser medium can be applied as optical gain in the active glass medium, and therefore composition of scattering light with amplification can be created. Scattering light is a product of spontaneous emission, whereas the amplification light is produced by stimulated emission [5]. The achievement of stimulated light emission in the lasing energy level depends on the optical pump power. If the power threshold of pumping is reduced, optical pumping power efficiency will be achieved as well as optical gain [6,7]. Several types of optical pumping, such as three-level pump system, quasi-three-level 912 nm Nd^{3+} laser at the $^4F_{3/2}$–$^4I_{9/2}$ transition [8], four-level crystal laser at 808 nm ($^4I_{9/2}\rightarrow{}^4F_{5/2}$ transition) [9] are capable to producing of lasing with multi-wavelength.

At three-level pump system, first, the light from the pump source excites the particle from the ground to the absorption band. Ideally, the particles

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that reach this state will quickly move to higher level, also called level two. The population inversion occurs at level two causing the particles to move from level two toward level one while emitting laser. The transition cycle (from ground state back to its origins was quickly reached) [10]. The optical pumping on quasi level four have metastable state among higher state and ground state. When pumping process is continuous, the particle accumulation occurs in the metastable state. This explains the particle population at the higher energy level is denser. The results are particle population in the ground state can pass to metastable state. A photon which has been same energy as energy gap of metastable state to ground state is emitted spontaneously, and which will in turn trigger attract the other atoms in the metastable state towards ground state. Consequently, photons having the same energy are discharged by atoms, so the lasing ends. [11,12]. The laser transitions obtained from three-level pumped was discussed by Kunna et al. [13]. The $Nd:LuVO_4$ crystal medium is utilised to produce 900 nm laser power based on $^4F_{3/2}\rightarrow{}^4I_{9/2}$ transition. The 1057 nm laser at $^4F_{3/2}\rightarrow{}^4I_{11/2}$ transition produced by the Nd^{3+} ion-doped on the borate glass medium is one type of laser-produced from a four-level optical pumping [14]. A laser diode is generally used as optical pumping source to obtain the solid-state laser. When compared with other types of pumping, the quantum efficiency of laser diode is higher [15]. As we know that the laser diode can be operated continuously, namely Q-switched, mode-locked or Q-switched and mode-locked wave mode [16]. The Q-switched operations as optical pumping have been applied on crystal laser medium like Nd, $Y:CaF_2$ medium pumped with Cr^{4+}:YAG [17], $Nd:YVO_4$ medium is pumped by Nd:YAG [18]. The continuous wave (CW) mode of laser diode has been widely used as pump source on 980 nm erbium-doped fiber amplifier (EDFA) [19], 808 nm laser source on $Nd:YVO_4$/LBO [20] and 1.8 µm laser fiber on Cr:ZnSe [21]. In general, the output power from CW laser mode is smaller if compared with Q-switched locking mode. It is attributed to utilisation of CW laser usually used on fiber laser [22], whereas Q-switched laser is used in pulse form with picosecond and nanosecond pulses repetition [17].

In the present study, optical pumping based on CW laser diode mode with the pumping source had been designed. Several supported components were employed on the pumped system. The output power of near-infrared (NIR) was measured by using lock-in amplifier.

2. Experimental

Experiments were conducted on several optical instruments to produce laser light using crystal gain medium. The optical pumping based on 805 nm laser diode with the maximum power 900 mW was used. This gradually reduced the light and a polariser was placed in front of the laser pump. Further, the medium was placed on the optical holder standing. Optical resonator consists of two mirrors established before and after of gain medium to produce light oscillation in the resonator. The laser light on 1064 nm wavelength is used as reference signal at resonator and for gain medium. In the gain medium, 1064 nm laser was reinforced at the same phase generated from the pumped optical medium. The photo luminescence (PL) of output laser from the resonator was recorded using two instruments: lock-in amplifier SR830 to measure the laser gain pumped and oscilloscope instrument used to determine the reference signal. The pumping instruments setup by resonator position and the experiment setup ares shown in Figure 1.

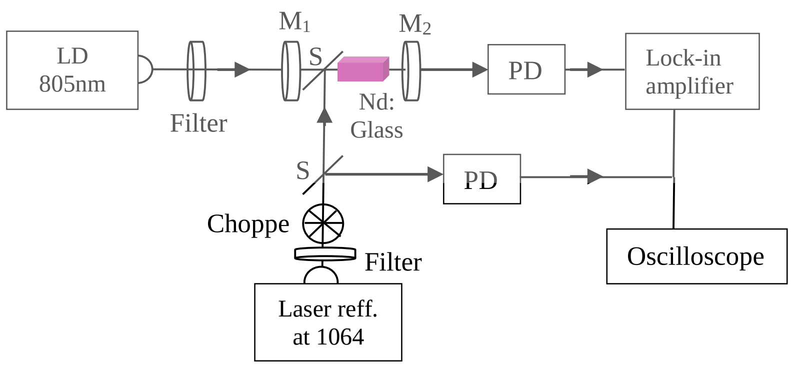

Figure 1. The detailed experiment of laser diode photopumped.

3. Results and discussion

3.1. Pumping and reference laser source

The maximum power of photopumped laser diode in this experiment was 900 mW with continuous wave (CW) mode and wavelength operation at 805 nm. Figure 2 shows the 805 nm laser spectrum used as the pumping source. The spectrum shows a single line with high peak from the basic intensity. The characteristics were consistent with those of Lu et al. [23] where laser beam produced from stimulated emission was a on single spectrum. The placement of the filter in front of pumping source served to polarise the laser beam in order for the light to be inserted into gain medium. The incident laser is controlled from pumping source to gain medium using polarisation-selective principle [24]. The output power of 805 nm laser absorbed pump power under different polarisation was measured using power meter 841-PE.

The photo luminescence of reference laser source at 1064 nm wavelength was used to compare the produced signal from the gain medium (1064 nm). The reference laser created the baseline signal for measurement of the laser output. Before measurement, the spectrum of reference laser was observed using Aurora 4000 GE—UV—NIR. The spectrum of reference laser with a single line at 1064 nm wavelength is shown in Figure 3, that the spectrum peak is very sharp, reflecting the light source is CW laser.

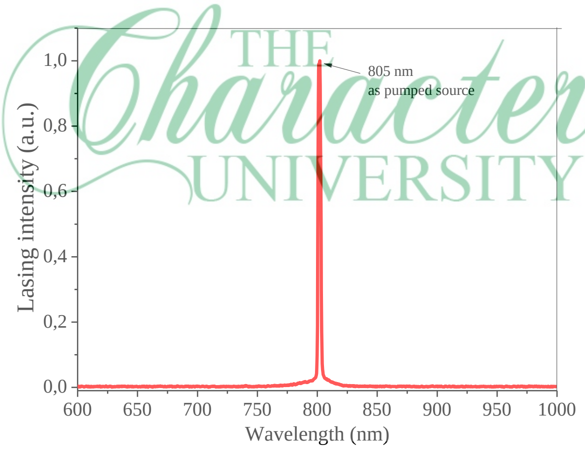

Figure 2. Single a photoluminescence of 805 nm laser diode as photopumping source on Nd^{3+} doped crystals.

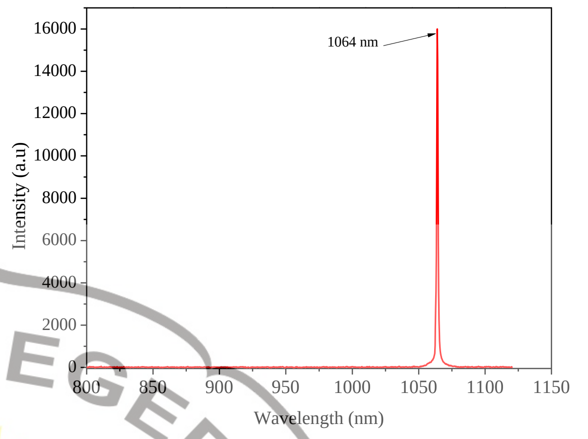

Figure 3. The 1064 nm laser spectrum as reference signal laser.

The frequency of reference laser should be the same as pumping generated. The output signal is connected the photodiode and forwarded to the lock-in amplifier. The 1064 nm reference signal is split by the beam splitter, and the signal inserted into the gain medium. The constructive interference between the reference signal with the produced signal by optical pumping has taken place in the gain medium. The output signal interference is recorded using lock-in amplifier and oscilloscope in voltage parameter.

3.2. Signal gain by $Nd:YVO_4$ and Nd:YAG laser medium

Laser gain medium based on $Nd:YVO_4$ and Nd:YAG crystal are used to demonstrate the performance of the pumping system. The laser medium was positioned on the track of interference signal and two mirrors were also placed on the left and right side of the medium. The output voltage characteristics of 1.0 wt.% $Nd:YVO_4$ laser as function of pump power source is shown in Figure 4. In the measurement, the reference signal (V_{reff}) passing through $Nd:YVO_4$ medium is 0.165 mV. Furthermore, the laser medium was pumped by 900 mW power at 805 nm LD and the output voltage was increased to 2.7 mV. It can be seen that the gain voltage from optical pumping achieved is 2.535 mV. However, the lasing in the viewer does not appear for pump power less than 151 mW. The output power at 151 mW is the threshold power by exciting electron at $^4F_{3/2}$ to $^4I_{11/2}$ but the transition is small for Nd^{3+} laser crystal [25].

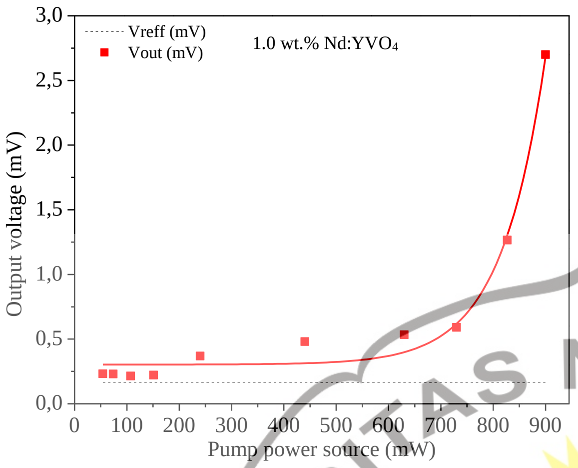

Figure 4. The measured variation of the output voltage at $Nd:YVO_4$ crystal as a function of absorbed pump power.

The laser gain measurement versus pump power source for $Nd:YVO_4$ medium is shown in Figure 5. The relationship between gain and pump power shows an exponential pattern where the measured voltage increases drastically at 630 mW to 730 mW power. The pump power is increased underway up to 900 mW. The $Nd:YVO_4$ gain medium occurs due to electron emission by photon stimulated from optical pump power at 805 nm. The laser emission occurred at ${}^4F_{3/2}\rightarrow{}^4I_{11/2}$ transition with fluorescence peak at 1064 nm [26]. The average gain between 151 mW to 54 mW shows data did not change when the optical gain is approximately at 2.7 dB. The maximum gain of $Nd:YVO_4$ medium is achieved at 24.278 dB for absorbed pump power at 900 mW.

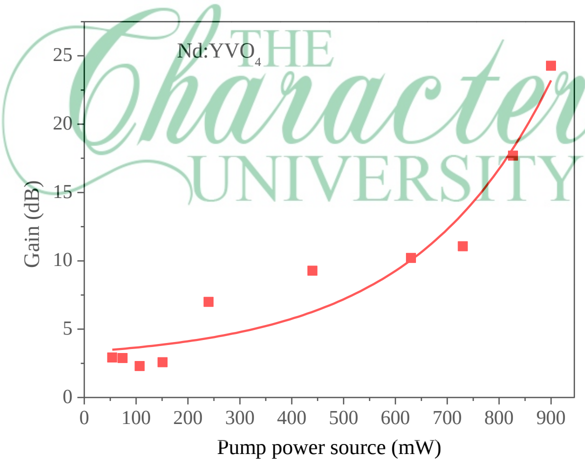

Figure 5. The optical gain of 1064 nm laser produced by $Nd:YVO_4$ crystal medium.

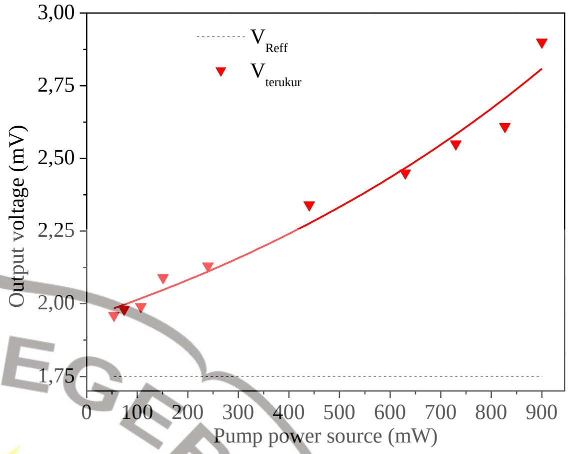

Figure 6. The measured variation of the output voltage at Nd:YAG crystal as the function of absorbed pump power.

The output voltage of 1064 nm laser on Nd:YAG crystal medium is investigated based on laser diodes having wavelengths around 805 nm. Figure 6 shows the measured voltage distribution versus pump power source. The measured reference voltage when the laser beam is passed through Nd:YAG crystal medium is 1.75 mV. Optical pumping at 900 mW and 54 mW maximum and minimum power are set. The incident pump is set at maximum power (900 mW) and the average of maximum output voltage achieved is 2.9 mV. The minimum average output voltage obtained is 1.96 mV when the incident pump power is set at 54 mW. The small measured output voltage indicates the optical reflectivity and the cavity length is still less than optimum [27,28]. A plane-plane resonator with 50 mm length of the cavity and 805 nm CW pump power source are generated at micro watt laser output at 1064 nm wavelength. The optical and slope efficiency are smaller than when optical pumping source is increased above 1 W. The misalignment of the resonate cavity causes up to 5% power loss. The gain medium is not wrapped with indium foil or held in a copper blocks, the thermal expansion in the crystal medium is unstable, lowering the efficiency of the slope.

The optical gain of Nd:YAG crystal at 1064 nm wavelength using 900 mW pump power is shown in Figure 7. The minimum and maximum output gain of Nd:YAG crystal is 0.98 dB and 4.4 dB respectively, obtained from given optical pump source at 54 mW and 900 mW respectively. The value of pump power source increases when the dB output gain is Nd:YAG.

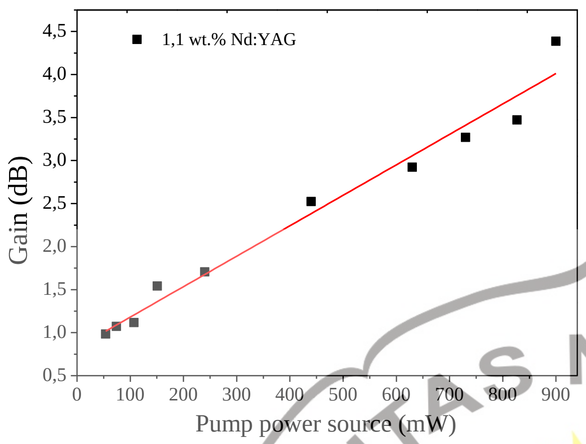

Figure 7. The optical gain of 1064 nm laser produced by Nd:YAG crystal medium.

4. Conclusions

The laser beam at 1064 nm wavelength is the output beam from the Nd:YVO_4 and Nd:YAG crystals when pumped with lased diode (LD) photopumped. The optical gain of laser output for both crystal medium is measured for variated absorbed pump power. The pumping source with CW mode of laser diode at 805 nm optical pumping is set at 900 mW maximum power. The 1064 nm reference signal is split using beam splitter, so the reflected signal is inserted into gain medium. The obtained signal output voltage of the Nd:YVO_4 laser is 2.7 mV for 900 mW maximum pumu power source. The obtained maximum output voltage of 1064 nm laser for Nd:YAG crystal medium is 2.9 mV for 900 mW maximum power. This experiment shows that Nd:YVO_4 crystal possess more potential at 1064 nm lasing compared with Nd:YAG crystal.

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