International Conference on Sensor, Sensor System, and Actuator ***(ICSSSA 2015)***
Bali, Indonesia, August 5-6, 2015

Comparative Continuous Wave (CW) Laser Diode Pumped of $Nd^{3+}:YVO_4$ and Nd^{3+}:YAG Crystals at 1.06 «m Emission Laser

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Abstract. A laser diode with continuous wave (CW) condition is demonstrated as photo pumped of Nd3+:YVO4 and Nd3+:YAG crystals laser. The laser emission was obtained at 1064 nm wavelength ($^4F_{3/2} \rightarrow {}^4I_{11/2}$ transitions) for 1.0 wt.% and 1.1 wt.% Nd3+ ion in YVO4 and YAG crystals respectively. The performances of the laser were observed under the 805 nm wavelength of laser diode end-pumped. The maximum average output power can be obtained by 190 mW absorption pump power. We observe that laser emission intensity and output power of Nd:YVO4 crystal were higher than Nd:YAG crystal, correspond to the increase of slope efficiency.

Keywords: Nd:YVO4, Nd:YAG, Laser diode, emission, fluorescence.
PACS: 42

INTRODUCTION

In the recent year, development of the optical laser technology was improved rapidly which accompanied with the presence of high efficient and average output power solid state laser. The solid state laser devices offer several application fields such as in medical handling, manufacture, technology sensors, communication, military and defense system and welding industry [1-3]. Several observations about high average power diode pumped solid state laser have been demonstrated using crystals of Nd:YAG, Nd:YVO4 and Nd:GdVO4 as laser medium [4-6]. The single frequency solid-state laser generation of Nd:YVO4 crystal at 1064 nm has been identified by C. Li et al. [7]. They are investigate the laser performance by using diode-pumped continuous wave (CW) Nd:YVO4 crystal. The maximum incident pump power of 900 mW was used to generate the average output power of 163 mW. The maximum output power and threshold laser power were directly affected by the transmission percentage of output coupler. The CW output power was slightly lower and threshold laser became higher when the output coupler transmission increases from 3% to 5% [7]. The Nd:YAG and Nd:YVO4 laser gain medium have been regarded as the most popular of laser to achieve high average power laser output operating at 1064 nm [8]. The Nd:YAG crystal offers several advantages such as high efficiency, good beam quality, high absorption coefficient, high thermal conductivity and effective grown in large crystal [9]. Whereas, the Nd:YVO4 crystal has the characteristic of large birefringence emits polarized and large stimulated emission cross section [10-11].

Laser operation of single frequency generation at 1064 nm wavelength by using YVO4/Nd:GdVO4 crystal and a diode-pumped continuous wave had been reported [12]. Recently, Brandus et al. [13] reported a fiber-coupled diode laser with $\lambda p \sim 812$ nm was employed as optical pumping of Nd:GdLuCOB single crystal. The average output power of 1.76 W was obtained for incident pump power of 5.49 W from an uncoated ZX-cut Nd-GdLuCOB laser medium. Moreover, K. Liu et al. [14] demonstrated a 885 nm LD direct pumping for Nd:YAG laser and yielded emission laser at 1064 nm.

In this work is demonstrated the direct pumping by using solid-state continuous wave (CW) laser diode. Under pumping 805 nm wavelength, the laser emission and average output power of Nd:YAG and Nd:YVO4 crystals were measured. The results were compared with absorbed pump power to obtain the slope efficiency and laser threshold of both crystals.

EXPERIMENT

The schematic diagram of the laser diode pump system is shown in Fig. 1 The Nd:YAG and $Nd:YVO_4$ crystals were pumped by laser diode at 0.5W output power and 805 nm central emission wavelength. A continuous wave (CW) all solid state laser diode system was used as pump source. The excitation wavelength could be arranged to achieve of range 800-810 nm by increasing temperature of the laser diode heat sink. The laser beam from LD mount was focused in an optical lens system (L1 and L2) to result the suitability of pump spot radius at the laser crystals. The two laser crystals based on Nd:YAG and Nd:YVO4 were used in this paper to compare the emission laser at 1.06 μm. In this experiment, a conventional Nd:YAG crystal with 1.1 at% Nd^{3+}-doped concentration and dimension of 2.5 x 2.5 x 0.6 mm^3 was compared to an a-cut oriented, 1.0 at% Nd^{3+}-doped concentration in YVO_4 crystal to be used as the laser medium. The dimension of Nd:YVO_4 crystal is 3 x 3 x 4 mm^3 which one side coated with HT at 808 nm/ AR at 1064 and 532 nm and another side with HR at 1064 and 532 nm. The flat broad band high reflective (BBHR) mirror was placed very close after medium crystal as output light lasing. The left-hand side of the BBHR mirror that near to crystal has high reflection coating at 750 – 850 nm (R>99.0%) while the right-hand side of the BBHR uncoated. The left hand-sides of medium crystal and BBHR mirror were serves as laser resonator to generate of the output laser beam. The output laser emission from BBHR mirror was captured by a 3648 pixels CCD linear array detector and recorded by Aurora4000 spectrometer in the region of 350-1100 nm. The emission wavelength center of both Nd:YAG and Nd:YVO_4 laser crystals was 1064 nm for maximum pump power. Moreover, the output power of laser emission at 1064 nm was detected with a photodiode 818-UV S/N 4064 Newport and recorded by using power meter (841-PE, Newport).

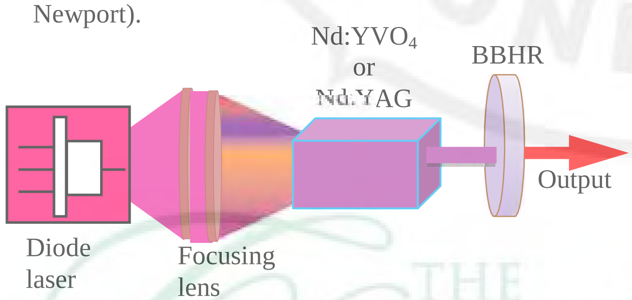

FIGURE. 1. Diagram of CW laser diode pump system

RESULTS AND DISCUSSIONS

The first step in this experiment is determine the fluorescence spectra of both Nd:YAG and NdYVO_4 crystals. The fluorescence spectra at 1064 nm was investigated with the conventional optical pumping as shown in Fig. 2. Nd:YAG laser typically emit near infrared transitions near 946 nm ($^4F_{3/2}\rightarrow{}^4I_{9/2}$) and 1064 nm ($^4F_{3/2}\rightarrow{}^4I_{11/2}$) respectively. These transitions correspond to that have been described by Koechner, et al. [15]. The different feature was occur in the Nd:YVO_4 spectra, which show a fluorescence spectra in this measurement centered at 1064 nm. Compared to Nd:YAG, the fluorescence intensity of Nd:YVO4 laser is most intense at 1064 nm laser. From Fig. 2 can be seen that the maximum output intensity of Nd:YVO4 crystal is more than two times higher if compared with the emission intensity of Nd:YAG crystal. This intensity is very high because of Nd:YVO_4 crystal has intra cavity for oscillate the pump light inside of the medium. As we know that the resonator cavity is needed to obtain of the overlap conditions by the emission wavelengths of the pump laser [16-17].

TABLE 1. Laser properties of Nd:YAG compared with Nd:YVO4 [12, 17-19]

Parameters	Nd:YAG	Nd:YVO4
Absorption coefficient (cm^{-1})	9.1	31.4
Pump wavelength,λ_p (nm)	807.5	808
Lasing wavelength,λ_l (nm)	1064	1064
Thermal conductivity, k ($Wm^{-1}K^{-1}$)	18.0	12.0
Thermal expansion, dn/dT (K^{-1})	6.14 x 10^{-6}	8.5 x 10^{-6}
Stimulated emission cross-section,σ_e (cm^2)	2.8x10^{-19}	2.5x10^{-19}
Fluorescence lifetime, τ (μs)	230	100
Threshold power, P_{th} (mW)	115	78
Linewidth (nm)	0.6	0.8
Effective wavelength, Δλ (nm)	2.2	1.8

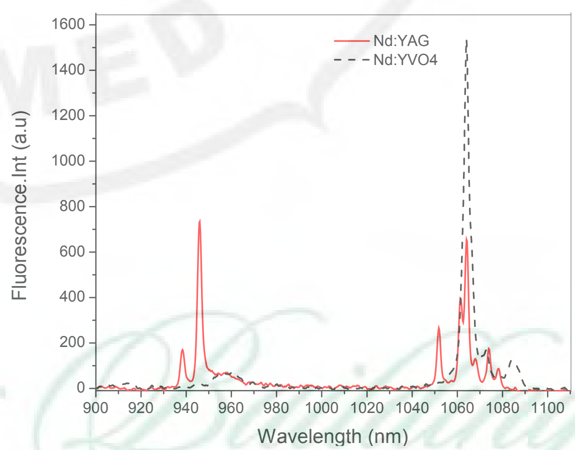

FIGURE 1. Lasing position at 1064 nm for Nd:YAG and Nd:YVO4 laser crystals

The average output power at 1064 nm for Nd:YVO_4 laser is shown in Fig. 3. The incident pump power in CW operation was used with pumping range starting from 8 mW to 78 mW as input power. A maximum output power was obtained up to 73 μW under absorbed pump power 78 mW. As shown in Fig.

3, the exponential pattern can be achieved from the relationship between total output power and absorbed pump power. The low threshold output for Nd:YVO_4 laser has been measured to be 12.4 mW. This threshold is very low for directly pump power due to the high of the pump power absorption at Nd:YVO4 crystal [20]. This condition is supported by the high absorption coefficient as shown in Table 1. By using a spectrum recorder to scan the single frequency generation laser at 1064, the magnitude of laser output intensity for Nd:YVO_4 crystal were yielded as shown in Fig. 4. The intensity curve versus absorbed pump power of Nd:YVO_4 laser is shows the similar trend to the output power curve in Fig. 3. It is clear that the low power laser under pump less than 100 mW can be realized by using the coated Nd:YVO_4.

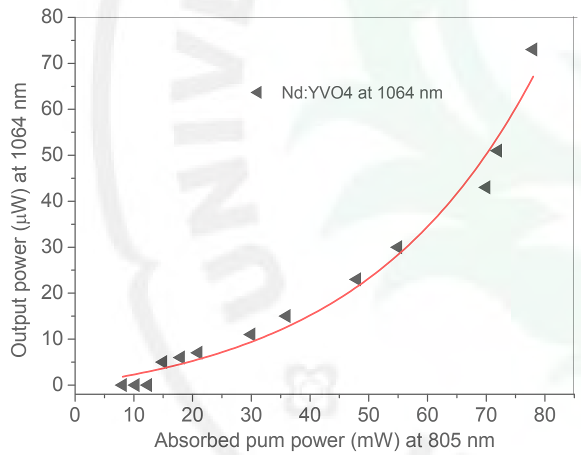

Fig. 3. Average output power at 1064 nm of Nd:YVO_4 pumped 805 nm

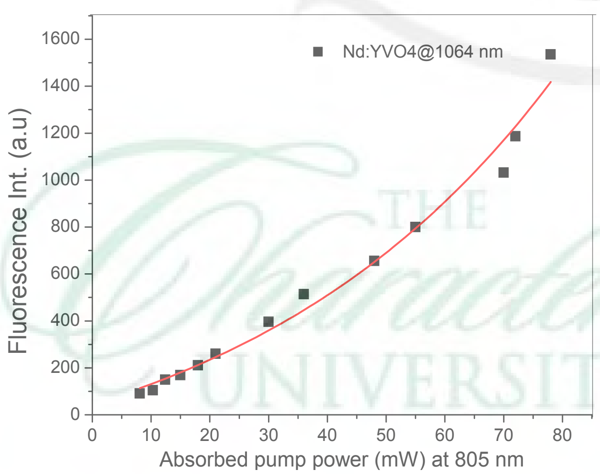

Fig. 4. Fluorescence intensity average at 1064 nm of Nd:YVO_4 crystal pumped by 805 nm LD

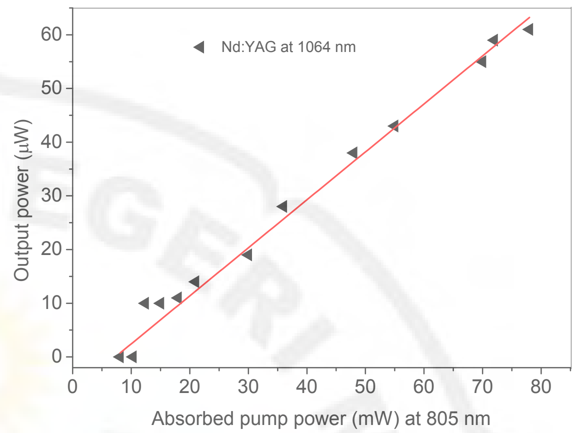

Fig. 5. Average output power at 1064 nm of Nd:YAG pumped 805 nm LD

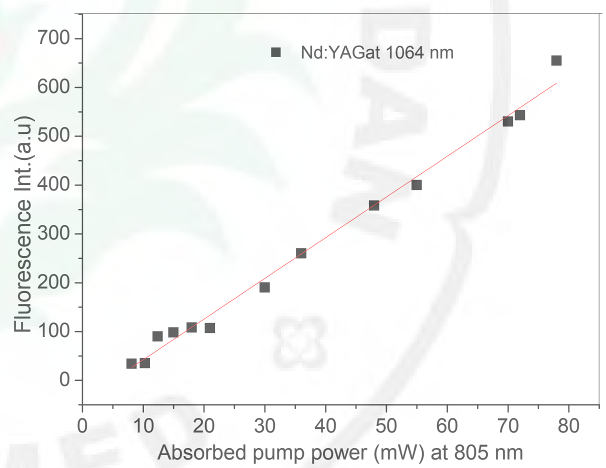

Fig. 6. Fluorescence intensity average at 1064 nm of Nd:YAG crystal pumped by 805 nm LD

At the same time, the average of output power and fluorescence intensity of the Nd:YAG laser were measured as shown in Fig. 5 and Fig. 6 respectively. The maximum output power can be achieved until 61 µW under absorbed pump power 78 mW. This is slightly lower than that the Nd:YVO_4 output laser. Fig. 5 and Fig. 6 shows the linear plot for the average output power and fluorescence intensity versus the absorbed pump power of the Nd:YAG laser. From Fig. 5, the laser threshold can be determined to be 10.3 mW. The difference between laser threshold may be due to different value of the stimulated emission-cross-section and the absorbed pump power varied of Nd:YAG and Nd:YVO_4 crystals respectively [21]. On other hand, Nd:YVO_4 crystal has wide absorption bandwidth, so that the sensitivity to the diode wavelength variation is low [20]. This explanation is supported by Nd:YVO_4 laser properties as shown in Table 1. We can see that the absorption coefficient of

$Nd:YVO_4$ crystal is relatively higher than Nd:YAG crystal, which is more three times larger than that of Nd:YAG. But, for the stimulated emission cross section, $Nd:YVO_4$ crystal has $2.5x10^{-19}$ cm^2, slightly smaller than Nd;YAG ($2.8x10^{-19}$ cm^2).

CONCLUSIONS

A comparison of Nd:YAG laser and coated intra cavity Nd:YVO4 crystals under the same optical pumping configuration is presented, which shows that $Nd:YVO_4$ is more intense than Nd:YAG for $^4F_{3/2} \rightarrow ^4I_{11/2}$ (1064 nm) laser operation. It is known that the absorption pump power at 805 nm wavelength of the $Nd:YVO_4$ is larger than that of the Nd:YAG crystal. This means that only a little proportion of the total pump energy was absorbed along the pump beam propagation.

ACKNOWLEDGMENTS

This work was partly supported by Hibah Bersaing program of General Director of Higher Education (DIKTI) 2014-2015.

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