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ICAPMA_2017 Emission cross section and optical gain of 1.06 ? m laser Nd3+ doped borate glasses Juniastel Rajagukguka,*, Bornok Sinagaa, Eidi Sihombinga, Mitra Djamalb, Jakrapong Kaewkhaoc aFaculty of Mathematics and Natural Sciences, Universitas Negeri Medan, 20221, Indonesia b Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Indonesia cCenter of Excellence in Glass Technology and Materials Science, Nakhon Pathom Rajabhat University, Thailand Abstract In this paper we develop the optical pumping system based on 805 nm laser diode as photo -pumped source. Laser with a wavelength of 1064 nm is used as reference source and passed in a laser glass medi um.

Laser glass medi um was synthesized from chemical compositions of (65-x)B 2O3-15Na2O-10PbO-5ZnO-5Li2O-xNd2O3 (with x = 0.05, 0.1, 0.5, 1.0, 2.0 and 4.0). The emission spectra confirms that there are three emission peaks located at 946 nm, 1064 nm and 1350 nm corresponding to 4F3/2 ? 4I9/2, 4F3/2 ? 4I11/2 and 4F3/2 ? 4I13/2 respectively.

The emission cross section relatively higher for the 4F3/2 ? 4I11/2 transition shows the compatibility of these glasses for near infra-red laser application. The measurements of optical gain had been carrie d out by using lock-in amplifier with voltage as output signal. From output voltage c onverted to optical gain in dB. The glass medium with 1.0 Nd3+ label was obtained the maximum optical gain with incident power 900 mW.

© 2018 Elsevier Ltd. All rights reserved. Selection and/or Peer-review under responsibility of 3rd International Conference on Applied Physics and Materials Applications. Keywords: Emission Cross Section; Optical Gain; Glasses 1. Introduction

Compact and high efficient solid-state near-infrared (NIR) laser are highly desirable for several applications including optical communication, laser light therap y and biomedical spectroscopy [1]. Neodymium (Nd 3+) ions doped borate glasses are the most prospective candidates for their broadband optical amplifiers.

* Corresponding author. Tel.: +62812-60786247; fax: +6261-66140002. E-mail address: juniastel@yahoo.com J. Rajagukguk et al./ Materials Today: Proceedings 5 (2018) 14998–15003 14999 As it is known the reason of Nd 3+ ions have been promising alternative used as optical amplifier is relation to generate of laser emission at wavelength around 946 nm, 1064 nm and 1350 nm [2].

On the other hand, the absorption bands of Nd 3+ ion in the region of UV-vis-NIR are great potentially as pumping source. Among Nd 3+ absorption band, a wavelength of 808 nm is laser diode that easy found as optical pumping source. So far, research related Nd3+ doped oxide glasses, such as tellurite, silicate, phos phate and borate are still focused at determine of physical and optical properties.

Moreover, the utilization of rare earth doped glass to be applied as broadband optical amplifier is dominated by erbium (Er 3+) at emission peak region 1.5 ? m [3]. Therefore, the developed a new region of emission band that produced by Nd 3+ doped glasses could be offered excellent lasing at 1.06 ? m and also as second telecommunication windows at 1.3 ? m.

Recent study reveals that borate glass is one of the most promising as host matrix of high concentration Nd3+ ions. In the present work, the laser amplification system based on optical pumping at 805 nm was designed. Gain medium of Nd3+ doped sodium borate glass was placed between two mirrors M1 and M2 respectively to reach optical gain in medium.

The 1064 nm laser source is used as reference signal to be amplified by optical pumping in glass medium. The aim of this experiment is to observe gain value of medium glass by optical pumping 805 nm. 2. Experiments The experiment schematic of optical amplifier based on Nd 3+: glass is shown in Fig. 1.

The optical pumping source is continuous wave 805 nm LD with a maximum output power of 1 W. The glass compositions that prepared in previous our works [4] were made as gain medium and placed in between two mirrors M1 and M2 as shown in Fig.1. The input mirror (M1) was made HR/HT @808/1064 nm, whereas M2 was HR@740-810 nm.

Further, the output signal is connected to a photodiode (PD1) and displayed in SR-810 lock-in amplifier. While the PD2 is used to detect the 1064 nm laser source is declared as a reference signal. Fig. 1. Diagram of optical amplification system at 1064 nm in Nd 3+ doped sodium borate glasses. M: mirror, S: beam splitter, PD: Photodiode. 3. Results and discussion Fig.

2 shows the emission spectra of Nd 3+ -doped sodium borate glass system with excitation source is 805 nm. The emission spectrum for similar host with excited source at 582 nm and 804 nm had been reported in our previous work [4]. As can be seen that the emission spectrum of glass samples consist of three bands.

The first position is located at approximately 904 nm with transition of 4F3/2 ? 4I9/2. The second position is lo cated at around 1064 nm with transition of 4F3/2 ? 4I11/2. The third position is located at 1327 nm to 1360 nm with transition of 4F3/2 ? 4I13/2.

The emission intensity at 1064 nm wavelength being the maximum emission peak and consistently occurs for all glass samples. From 1064 nm emission spectra is known th at the emission intensity increases with increase in Nd 3+ concentration from 0.05 mol% up to 1.0 mol%, and then decr eases drastically at 2.0 mol% as shown inset Fig. 2. It S2 S1 Chopper M1 PD2 PD1 Laser reff.

at 1064 LD 805nm M2 Lock-in amplifier Oscilloscope Nd: Glass 15000 J. Rajagukguk et al./ Materials Today: Proceedings 5 (2018) 14998–15003 is explains that the concentration quenching is obtained beyond 1.0 mol% due to energy transfer processes among dopant ions [5]. 800 1000 1200 1400 1600 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.05Nd 0.1Nd 0.5Nd 1.0Nd 2.0Nd 4.0Nd 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 Emission Int. (a.u) Glass Samples Exc. 805 nm Emission Int. (a.u) Wavelength (nm) BNPZLiN1 BNPZLiN2 BNPZLiN3 BNPZLiN4 BNPZLiN5 BNPZLiN6 ? exc = 805 nm 4F3/2 ? ? ? ?? 4F3/2 ? ? ? 4F3/2 ? ? ? Fig. 2.

Emission spectra of Nd3+ doped sodium borate glasses with ? exc = 805 nm. 200 400 600 800 1000 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 200 400 600 800 1000 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 Intensity Normalized (a.u) Time (? s) BNPZLiN1 BNPZLiN2 BNPZLiN3 Intensity Normalized (a.u) Time (? s) BNPZLiN4 BNPZLiN5 BNPZLiN6 Fig.3. Luminescence lifetime of Nd3+ doped sodium borate glass system for Nd 3+ concentration at 1.0 mol.%; 2.0 mol.% and 4.0 mol.%. For 0.05 mol.%; 0.1 mol.% and 0.5 mol.%

concentrations are inset. The exponential decay curves of Nd 3+ -doped sodium borate glass system with transition from 4F3/2 excited state are recorded at room temperature by exciting at 805 nm so urces and are shown in Fig. 3. It is described that the decay curve shows the single exponential function.

The si milar curves for BNPZLiN1to BNPZLiN3 are shown in inset Fig. 3. From the decay curves , the measured luminescence lifetime (? exp) for 4F3/2 excited state have been determined for all glass samples and are shown in Table 1. The radiative lifetimes have been calculated based on absorption spectra [5] and Judd-Ofe lt theory and are presented in Ta ble 1.

The quantum efficiency (?) are determined by directly comparing the experimental and radiative lifetime (? exp/? R) and presented in Table 2 together with other value of borate glass was reported before [6]. The experimental lifetime values are shows the varying trends which are decrease from 54.26 ? s for BNPZLiN1 to 14.13 ? s for BNPZLiN2, then increase to 63.53 ? s when J. Rajagukguk et al./

Materials Today: Proceedings 5 (2018) 14998–15003 15001 the Nd3+ ion concentration increase to 0.5 mol% (BNPZLiN4). The concentration quenching effet on increasing of lifetime is associated to the increase of transfer energy processes among Nd 3+ ions by way of cross relaxation [7]. The behaviour of lifetime is found to reduced when the Nd 3+ ion concentration increased from 1.0 mol% to 4.0 mol%. Table 1.

Calculated radiative lifetime (? R) Experimental radiative lifetime (? exp), quantum efficiency (?) of 4F3/2 ? 4I11/2 transition of Nd3+ doped sodium borate glasses. No Initial Glasses ? ? ? ? ? (%) 1 BNPZLiN1 (0,05Nd 3+) 69 54.26 78.64 2 BNPZLiN2 (0,1Nd 3+) 69 14.13 20.48 3 BNPZLiN3 (0,5Nd 3+) 97 63.53 65.49 4 BNPZLiN4 (1,0Nd 3+) 89 55.63 62.51 5 BNPZLiN5 (2,0Nd 3+) 130 44.01 33.85 6 BNPZLiN6 (4,0Nd 3+) 142 23.69 16.68 8 Bi-30, Gupta (2014) [6] 169 83.3 49.0

Radiative properties such as effective bandwidth (?? eff), branching ratio (? R) and transition probability of radiative (A R) have been calculated and collected in Table 2. From the radiative parameters can be found the stimulated emission cross section (? e) by using of Fuchtbabauer-Ladenburg method [8]:)',(28 4 bJaJA effcn p em ?? ? ? ? ? (1) Where ? p is the peak wavelength of the emission peak, c is the speed of light, n is the refractive index and A(aJ, bJ') is the radiative transition probability. The 4F3/2 ? 4I11/2 transition at wavelength of 1064 nm is the most active luminescence if compared with other transition at Nd 3+ doped Borate glasses.

Consequently, this glass medium that doped Nd3+ ion has the potential to be used as a laser amplifier at 1064 nm wavelength. This result is supported by the value of radiative transition probability (A R) where the maximum result is achieved at 4F3/2 ? 4I11/2 transition for all of glass sample. From the equation (1), the emission cross section of Nd

3+ doped borate glasses for 4I11/2 transition were obtained and collected in Table 2.

From th e dates have been confirmed that the stimulated emission cross section for 4F3/2 ? 4I11/2 transition decreases with increasing Nd3+ ion concentrations. However the values of the emission cross section for all prepared glasses are higher when compared with other samples [8]. As we have known that the stimulated emission cross section is depends on radiative transition probability (AR) and effective line width (?? eff) fluorescence.

From Table 2 can be seen that BNPZLiN1 have the higher radiative transition probability and lower effective line width for 4F3/2 ? 4I11/2 transition. So that can produce the higher stimulated emission cross section. Besides the 4F3/2 ? 4I11/2 transition, the 4F3/2 ? 4I9/2 and 4F3/2 ? 4I15/2 transitions are also generating emission cross section as shown in Table 2.

The maximun ? em for 4F3/2 ? 4I9/2 and 4F3/2 ? 4I15/2 transitions are 3.93 x 10 -20 cm2 and 6.04 x 10-20 cm2 respectivly and achieved by BNPZLiN2 sample. The output laser characteristics which is a combined of the reference signal with incident pumped for BNPZLiN glasses are presented in Fig. 4. The measurement result by using SR SR-810 lock-in amplifier is displayed in voltage output (in mV).

The output of reference voltages was different for each BNPZLiN sample because of several factor, such as differences in thickness of glass, surface flatness and also density of the glass samples. The reference signal voltage is maintained consistently during pumping process so that the output voltage of optical gain at 1064 nm wavelength can be obtained.

In this experiment, the range of incident pump power is 54 mW to 900 mW. From Fig. 5 can be seen that for BNPZLiN2, BNPZLiN3, BNPZLiN4, BNPZLiN5 and BNPZLiN6 glasses, the output laser was found to increase with increasing of pump power. Whereas, for BNPZLiN glass did not found the output voltage of laser when pumped by 805 nm laser diode. The gain enhancement of maximum output laser is 1.05 mV achieved by BNPZLiN3 glass and followed by BNPZLiN4 is 0.75 mV.

The results are consistent to the emission intensity previously, where emission intensity of both BNPZLiN3 and BNPZLiN4 to be strongest compare with other glass medium. Table 2. Emission peak position (? p), effective line width (?? eff), stimulated emission cross section (? e(? p)), branching ratio (? R), radiative transition probability (AR) for the 4F3/2 ? 4I11/2 transition. Glasses ? p (nm) ?? eff (nm) AR (s-1) ? R (%) ? e x10-20 (cm2) Exp. Cal.

BNPZLiN1 1066 27.99 7869.67 0.55 0.54 18.58 BNPZLiN2 1064 40.498 8052.90 0.69 0.56 13.04 BNPZLiN3 1064 38.757 5677.52 0.73 0.55 9.61 BNPZLiN4 1064 42.74 5823.98 0.74 0.52 8.94 BNPZLiN5 1064 45.52 3686.30 0.77 0.48 5.31 BNPZLiN6 1064 42.80 3333.85 0.86 0.48 5.11 ZANP2 [8] 1063 28.13 2086.8 0.63 0.53 3.24 0 100 200 300 400 500 600 700 800 900 3,0 3,5 4,0 4,5 5,0 5,5 6,0 6,5 7,0 7,5 8,0 Vref = 2,85 mV Vref = 2,91 mV Vref = 4,45 mV Vref = 5,4 mV BNPZLiN6 BNPZLiN4 BNPZLiN3 BNPZLiN5 Output Voltage (mV) Incident pump power (mW) BNPZLiN2 Vref = 6,8 mV Fig. 4.

Measured output voltage in lock-in amplifier versus incident pump power for Nd 3+ doped sodium borate glasses. 0 100 200 300 400 500 600 700 800 900 0,0 0,2 0,4 0,6 0,8 1,0 1,2 1,4 1,6 1,8 2,0 2,2 BNPZLiN2 BNPZLiN3 BNPZLiN4 BNPZLiN5 BNPZLiN6 Gain (dB) Incident pump power (mW) Fig. 5. Internal optical gain versus incident pump power for Nd3+ doped sodium borate glasses. J. Rajagukguk et al./

Materials Today: Proceedings 5 (2018) 14998–15003 15003 The characteristics of laser output at wavelength of 1064 nm versus incident pump power are shown in Fig. 5. It can be seen that the optical gain of output laser increas es gradually with the increament of the pump power during pumping process up to 900 mW. The maximum output in decibel (dB) for BNPZLiN2, BNPZLiN3, BNPZLiN4, BNPZLiN5, BNPZLiN6 glasses are 0.71, 1.84, 2.03, 0.86, and 0.98 respectively. As shown in Fig.

5, the BNPZLiN4 glass can generating the strongest 1064 nm laser for pumping range 54 mW to 900 mW. However, be attention is BNPZLiN3 glass (0.5 mol.% Nd 3+) which has an increasing trend during and after the pumping of 900 mW. Whereas the BNPZLiN4 glass tends decrease after pumping of 900 mW. 4. Conclusion We have demonstrated the optical pumping experiment based on 808 nm CW laser diode as pumping source and Nd3+ doped borate glass as laser medium.

Laser with a wavelength of 1064 nm is used as reference source and is fixed. The optical gain for 1064 nm laser was successfully obtained with 900 mW incident pump power. The maximum output laser was achieved by BNPZLiN4 glass with 2.03 dB output gain. For BNPZLiN3 is known that the optical gain consistently increased during and after the optical pumping 900 mW. References [1] W. Fan, S. Chen, L.

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