Grain size distribution for optimized random laser emission in Nd^{3+}:YVO_4 powder pellets

J. M. Giehl, and N. U. Wetter
Centro de Lasers e Aplicações, IPEN-CNEN/SP, Av. Prof. Lineu Preses, 2242, São Paulo, SP,Brazil
nuwetter@ipen.br

Abstract: This work demonstrates a fivefold increase in laser efficiency of an Nd^{3+}:YVO_4 random laser by using mixtures of grain sizes.
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1. Introduction

Random lasers (RLs) are miniature sources of stimulated emission in which the feedback is provided by scattering in a gain medium [1]. The investigation of lasing action in a large variety of disordered materials including highly scattering powders, films, colloidal dye solutions, human tissues, etc. is a subject of high interest with important applications such as three-dimensional imaging and detection of cancer tissue and photonic coding and encryption [2-4]. Potential applications require optimization of random laser performance [5].

In a first step, our group published previously a work showing amplified spontaneous emission in Nd^{3+}:YVO_4 crystal powder [6]. In a second step, we published a complementary work [7] to find the optimal parameters of particle size and applied pressure to obtain the highest random laser amplification from Nd^{3+}:YVO_4 powders prepared as pressed pellets.

The aim of this work is to further optimize the parameters for the RL pellets, this time by using different grain size mixtures. The hypothesis is that pure mixtures of the same grain size do not generate as high output powers as mixtures that use small and big grain sizes together. All pellets were prepared under optimized pressure as demonstrated in [7].

2. Sample preparation and experimental setup

Pieces of an Nd^{3+}:YVO_4 crystal were grinded and the powder sieved by means of differently sized mesh grids to obtain ranges of different particle sizes (see table 1). After this first procedure isopropyl alcohol was mixed with the powder produced, stirred for 5 minutes using ultrasound, sieved again and then dried for a period of 24 hours. All samples were produced using approximately 60 mg of powder pressed at a pressure of 255MN/m^2 with a diameter of 7 mm. Three pellets were produced per grain size. Pellets of Group A were produced accordingly to the procedure outlined above. Their standard deviation is shown in brackets.

Table1. Samples of Nd^{3+}(1.33mol%): YVO_4 pellets and average particle size.

Group A	**Average particle size and STD**	**Group B**	**Average particle size and STD**
A_1	(6 ± 4) µm	**B_1**	(8.5 ± 8.1) µm
A_2	(28 ± 19) µm	**B_2**	(33 ± 32) µm

Pellets of group B have a much bigger standard deviation. Those pellets were produced by not using isopropyl alcohol. As we found out, the electrostatic forces attract the small particles to the larger ones, when not washing the particles with alcohol, in a manner that they are retained even within the much larger mesh grids.

The pellets were pumped at room temperature using a laser fast-axis-collimated diode in quasi-continuous mode operating at 808 nm with 5 Hz repetition rate and 150 µs pulse width. The 100 W diode beam is first expanded along the fast axis (y-axis) by two cylindrical lenses with focal lengths of f_1 = –13 mm and f_2 = –25 mm and then focused onto the sample with a spherical lens f_3 = 20 mm generating a square focus of 5.33 mm^2 [6-8]. The amplified stimulated emission produced from the pellet, measured in the backscattered direction, was attenuated by a neutral density filters and collected by an optical fiber. A spectrometer (Ocean Optics, model HR 2000) with 0.11

nm resolution was used for spectral acquisition. The following results refer to the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ transition in neodymium [6-8].

3. Results and discussions

Fig. 1 and Fig. 2 show SEM images of the samples A_1, B_1, A_2 and B_2, respectively. It can be seen that the treatment without isopropyl alcohol permits that smaller particles cluster around the larger particles. The difference amongst both treatment methods is less pronounced in Fig. 1 because at this small sieve size a large amount of small particles does not pass anymore through the mesh grid even when using the alcohol washing method.

The sample B_2 with average particle size of (33 ± 32) µm showed the highest signal amplitude of all four sample sizes, which is about 10 times higher when compared to the smaller particle size of sample B1 (8 ± 4) µm. The washed sample A_2 with average particle size (28 ± 19) µm showed a higher signal amplitude, about 2.5 times higher, when compared to the smaller particle sizes A1 (6 ± 4) µm. In Fig. 3, the difference in output power, achieved by using both methods, is demonstrated.

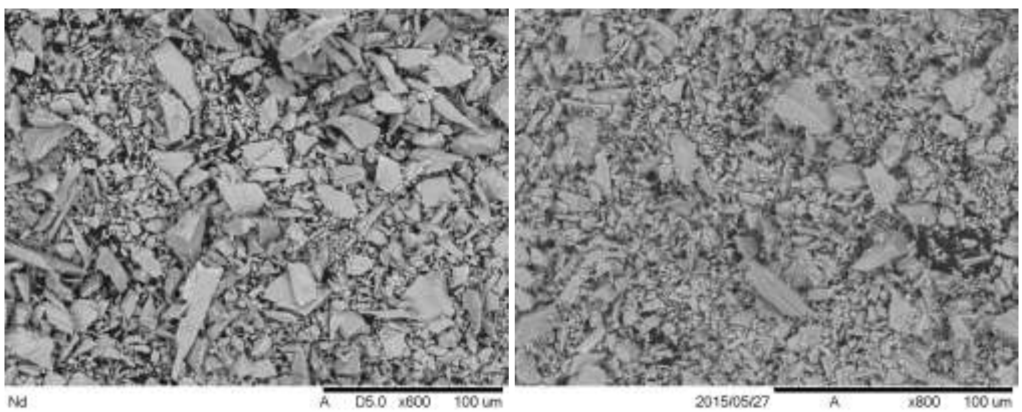

Fig. 1 – SEM of a) A_1 and b) B_1 powders before producing the Nd^{3+}:YVO_4 pellets.

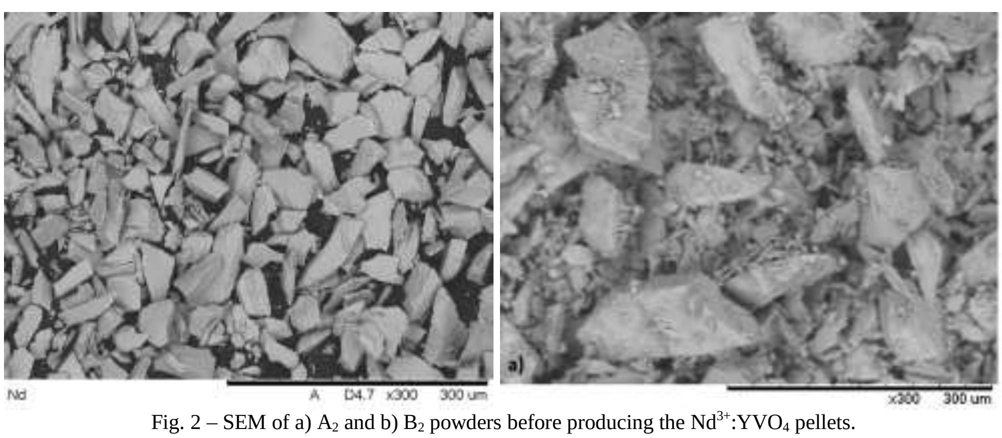

Fig. 2 – SEM of a) A_2 and b) B_2 powders before producing the Nd^{3+}:YVO_4 pellets.

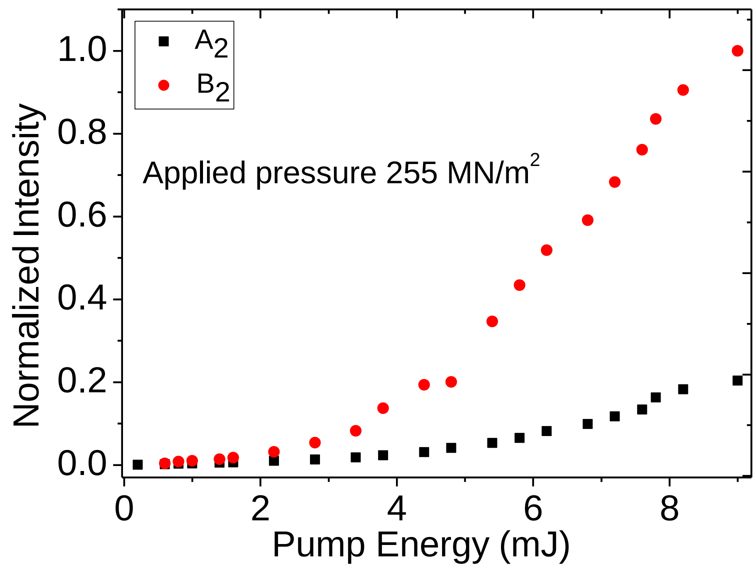

Fig. 3 – Normalized intensity of the Random Laser emission versus the incident laser pump energy for the samples of homogenous grain size (A2) and mixed grain size (B2). The results refer to the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ transition (1064 nm) of neodymium.

When comparing both samples, with (A2) or without (B2) treatment using isopropyl alcohol, it is clearly observed that the sample B_2 shows a more than five times larger amplification than A_2.

4. Conclusion

Pressed pellets of Nd^{3+}:YVO_4 powder have been prepared using different grain size distributions and applied pressure of 255 MN/m^2. Their random laser emission at 1064 nm was analyzed under high-power diode-pumping at 808 nm. The optimization resulted in an approximately five times higher output power when compared to previous samples of narrow grain size distribution.

5. Acknowledgments

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4. References

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