Relationship between coherent backscattering cone and the study of the random laser emission of Nd^{3+}:YVO_4 powders changing the particle size and applied pressure

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Abstract: In this work we present the optimal parameters of particle size and applied pressure for the preparation of Nd^{3+}:YVO_4 pellets that result in maximum random laser emission.

OCIS codes: (290.5850) Scattering, particles; (290.1350) Backscattering; (140.3380) Laser materials

1. Introduction

A major advantage of random lasers over regular lasers is that their production is cheap and the required technology very simple [1]. Also, random lasers may be produced from a huge range of different materials such as semiconductor nanoparticles, films, colloidal dye solutions, highly scattering powders, polymers, organic materials and biological tissues.

Potential applications require optimization of random laser performance [2]. M. A. Noginov et al. [2] have studied the dependence of random laser emission in $NdSc_3$ $(BO_3)_4$ powders on the particle size. To our knowledge, there are no references that study the effects of pressure applied to pellets used for random lasers. The aim of this work is to find 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.

2. Sample preparation and experimental setup

A Nd^{3+}:YVO_4 crystal was grinded and the powder sieved by means of differently sized mesh grids to obtain ranges of different particle sizes. About 50 milligrams of powder was pressed at different applied pressures (see Table 1) into pellets of 7 mm diameter. Three pellets were produced per grain size and applied pressure.

Table1. Particle sizes and applied pressures of Nd^{3+}(1.33mol%): YVO_4 pellets.

Particle size	**Applied pressure**
$10\ \mu m \leq x \leq 20\ \mu m$	51 MN/m^2, 255 MN/m^2
$75\ \mu m \leq x \leq 106\ \mu m$	51 MN/m^2, 255 MN/m^2, 510 MN/m^2
$x \geq 425\ \mu m$	255 MN/m^2

The pellets were pumped at room temperature using a laser diode in quasi-continuous mode operating at 808 nm with 5 Hz repetition rate and 150 µs pulse width. The diode beam is first collimated by two cylindrical lenses with focal lengths of –13 mm and –25 mm, respectively, and then focused onto the sample with a spherical lens f = 20 mm [3] generating a focus of 5.33 mm^2. The amplified spontaneous emission (ASE) from the pellet, measured in the backscattered direction, was attenuated by a neutral density filter and collected by an optical fiber. A spectrometer (Ocean Optics, model HR 2000) with 0.11 nm resolution was used for spectral acquisition.

3. Results and discussions

Different from a previously published work by our group [3] where the pressure was not varied during the pellet fabrication, we now observed ASE at low pressures independent of the position of the sample (i.e., at the center or edge of the sample), showing better control of the sample preparation.

Increasing the pump energy gradually, a threshold pump intensity was observed, at which a sharp ASE line at the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ transition (1064, 32 nm) appears [3, 4] (See Fig. 1). The following results refer to the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ transition.

In Fig. 2a the normalized intensity of the ASE is shown versus incident laser pump energy for the samples with particle size of $75 \leq x \leq 106$ µm and for different applied pressures. One can observe maximum intensity for an intermediate pressure of 255 MN/m^2. The sample submitted to the pressure 51 MN/m^2 presented 80% smaller ASE intensity. The sample submitted to the highest pressure of 510 MN/m^2 presented a 70% smaller value.

In Fig. 2b, three different particle sizes, as described in Table 1, were pressed at the same pressure of 255 MN/m^2. Particle sizes of $75 \leq x \leq 106$ µm show the highest increase in signal amplitude, which is about 10 times higher compared to the smallest particle sizes of $10 \leq x \leq 20$ µm. The sample with the bigger particle size ($x \geq 425$ µm) shows a decrease of ASE intensity of about 70% of the maximum value.

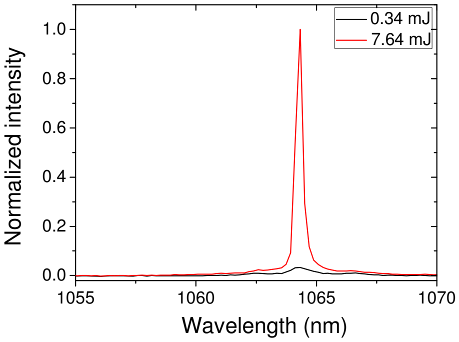

Fig. 1. ASE spectra for the sample with particle size between $75 \leq x \leq 106$ µm,with an applied pressure of 255MN/m^2. The figure shows the sample's ASE for two different diode laser pump energies; 0.34mJ (below threshold; black line) and 7.64mJ (above threshold; red line).

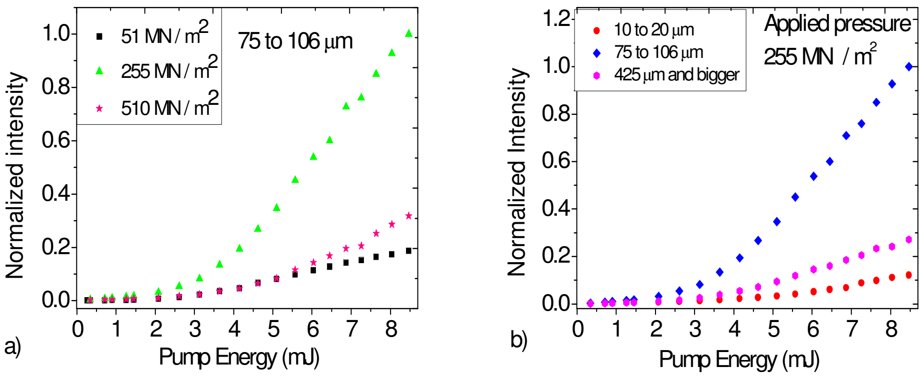

Fig. 2 – a) Normalized intensity of the ASE versus the incident laser pump energy for a particle size of $75 \leq x \leq 106$ µm for 3 different applied pressures. b) ASE versus the incident laser pump energy for the samples with 3 different particle sizes at constant applied pressure of 255 MN/m^2.

In Fig. 3a the normalized backscattered intensity is shown versus angle for the samples with particle size of $75 \leq x \leq 106$ µm and for different applied pressures. In Fig. 3b the normalized backscattered intensity is shown for three different particle sizes pressed at the same pressure of 255 MN/m^2.

The transport mean free path l_t was achieved by using the following two equations which describe the normalized backscattered intensity of the diffusive (α_d) and the coherent (α_c) backscattered light [5].

$$\alpha_d(\theta) = \frac{\mu\left(\frac{z_0}{l_t} + \frac{\mu}{\mu+1}\right)}{\frac{z_0}{l_t} + \frac{1}{2}} \qquad (1)$$

$$\alpha_c(\theta) = \frac{\frac{\left(1 - e^{-2qz_0}\right)}{ql_t} + \frac{2\mu}{(\mu+1)}}{2\left(\frac{z_0}{l_t} + \frac{1}{2}\right)\left(ql_t + \frac{(\mu+1)}{2\mu}\right)^2} \qquad (2)$$

Where $\mu = \cos(\theta)$, $q = k|\sin(\theta)|$, k is the wave vector of the incident light and $z_0 = l_t \cdot \frac{2}{3}$ is the extrapolation length.

In Table 2 and 3 the transport mean free path was calculated with above equations and fitted to the data from Figures 3a and 3b.

Table 2. Values of the transport mean free path of different pellets.

Particle size of 75 to 106 µm with different applied pressure	**Transport mean free path**	**Different particle size with 255 MN/m^2 applied pressure**	**Transport mean free path**
51 MN/m^2	23 µm	10 µm ≤ x ≤ 20 µm	16 µm
255 MN/m^2	28 µm	75 µm ≤ x ≤ 106 µm	26 µm
510 MN/m^2	26 µm	x ≥ 425 µm	35 µm

According to reference [2, 6] random lasers operate in the diffusive regime when $\lambda < l_t << L$, where λ is 0.6328 µm and L is the smallest linear size of the random laser medium. Our results are in agreement with this condition, as see table 2.

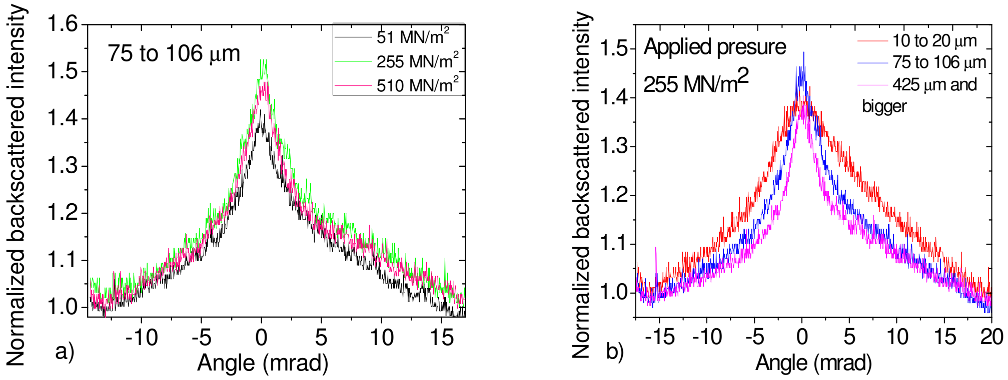

Fig. 3 – a) Normalized backscattered intensity versus the angle for a particle size of 75 ≤ x ≤ 106 µm as a function of 3 different applied pressures. b) Normalized backscattered intensity versus the angle for the samples as a function of particle sizes at constant applied pressure of 255 MN/m^2.

4. Conclusion

Pressed pellets of Nd^{3+}:YVO_4 powder have been prepared using different pressures and grain sizes and their random laser emission at 1064 nm has been analyzed under high-power diode-pumping at 808 nm. An optimal pressure of 255 MN/m^2 is found and the optimal particle size is 75 ≤ x ≤ 106 µm. This optimization resulted in an approximately 50x improvement when compared to previous results.

5. Acknowledgments

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6. References

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