Optimized grain size distributions for maximum efficiency in neodymium doped powder random lasers

N. U. Wetter, J. M. Giehl, F. Butzbach, D. Anacleto, G. De Simone, E. Jimenez-Villar
Centro de Lasers e Aplicações, IPEN-CNEN/SP, Av. Prof. Lineu Preses, 2242, São Paulo, SP,Brazil
nuwetter@ipen.br

Abstract: We show that polydispersed powders can have much higher random laser output power and efficiency than monodispersed powders. A more than 50% slope efficiency is achieved by using highly doped Nd:YVO_4 powders composed of average grains size of 50 μm and 10% volume fraction of grains below 1 μm. We demonstrate that the smaller particles, trapped between large particles, serve as gain centers whereas the large particles control the light diffusion into the sample. A detailed light diffusion analysis of the samples explains the observed differences.

1. Introduction

Typical applications of random lasers (RLs) are speckle-free imaging, display technology, encrypting, cancer detection, remote-sensing, and distributed amplification [1]. In comparison to standard lasers, the production of random lasers is cheap and the required fabrication technology is simple. There is an almost infinite combination of liquids and powders that can be used for RLs [2]. Potential applications require improvements in beam brightness and laser efficiency. The issue of laser beam brightness has been addressed before by our group [3]. A possible solution for the laser efficiency is the topic of this work. Laser action in micro powders of Nd^{3+}:YVO_4 has been shown before by our group [4]. We detected better performance in polydispersed powders that can be described as systems consisting of a large volume fraction of large particles and a small volume fraction of much smaller particles which are trapped in between the larger particles (Fig. 1a, 1b). We hypothesize that the smaller particles create regions with very short transport mean free path and therefore concentrate the light. The absorption mean free length within these regions is much smaller than within the bigger particles, therefore, these regions act as gain centers inside the random laser. The participation of the smaller particles on the transport mean free path is negligible.

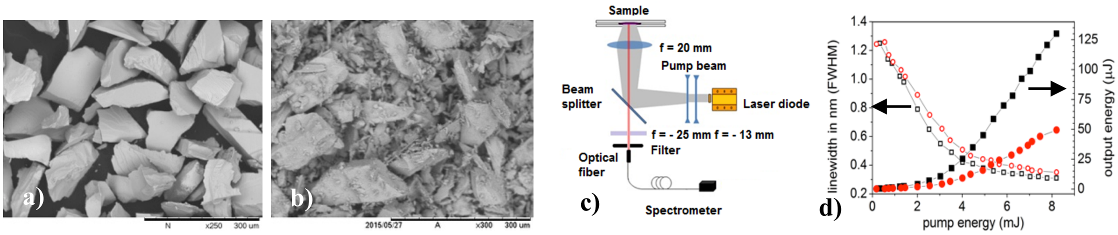

Fig. 1: SEM images of Nd^{3+}:YVO_4 powders from monodispersed samples (a) and polydispersed samples (b). (c) Laser set-up. Higher random laser output of polydispersed powders (d; black squares).

2. Results and discussion

In order to explain the observed results we measure volumetric powder grain size distribution, absorption spectra and transport mean free path of pressed powder pellets. We then calculate the fill fraction of the pellets, the mean photon path length for backscattering, the microscopic absorption length and, finally, the mean number of scattering events for monodispersed and polydispersed samples. While the mean photon path length for backscattering is similar in both samples, the number of scattering events is significantly higher in the polydispersed samples, indicating a higher pump energy density. The increase in output power for these samples is almost 160% when compared to the monodispersed samples (Fig. 1c, 1d). This indicates that the smaller particles, placed within the void spaces between the bigger particles, play a crucial role in improving the random laser performance. The large difference in output power can be explained by analyzing the light diffusion properties of the samples as a whole as a function of the measured scattering mean free path.

3. References

[1] R. C. Polson and Z. V. Vardeny. Appl. Phys. Lett. **85**, 1289 (2004).
[2] D. S. Wiersma, Nat. Phys. **4**, 359-367 (2008).
[3] K. C. Jorge et al., Appl. Opt. **55**, 5393 (2016).
[4] Vieira, R. J. R., Gomes, L., Martinelli, J. R. and Wetter, N. U. Opt. Express 20, 12487-12497 (2012).