Intracavity Raman lasers at 990 nm and 976 nm based on a three-level Nd:YLF fundamental laser

Dimitri Geskus,[1] Jonas Jakutis Neto,[1] S.M. Reijn,[1] Helen M. Pask,[2] Niklaus U. Wetter,[1]
[1]Centro de Lasers e Aplicações, IPEN/SP, Av. Prof. Lineu Prestes, 2242 São Paulo, SP, Brazil
[2]MQ Photonics, Department of Physics and Astronomy, Macquarie University, Sydney NSW 2109, Australia
Author e-mail address: nuwetter@ipen.br

Abstract: This is the first time that significant Stokes output power of 0.88 W at 990 nm has been achieved using a three-level fundamental transition (quasi-cw Nd:YLF laser) with stimulated Raman scattering in a KGW crystal.
OCIS codes: (140.3530) Lasers, neodymium, (140.3550) Lasers, Raman, (190.2620) Harmonic generation and mixing.

1. Introduction

Past decades have seen crystalline Raman lasers evolve into practical and efficient laser sources. The first Raman lasers operated in the q-switched regime [1, 2] to provide sufficiently-high fundamental intensities to achieve positive net Raman gain. Nowadays, crystal growth and coating technologies have advanced enormously, such that resonator losses are sufficiently low to permit CW Raman laser operation [3]. The wavelength-agile character of Raman lasers, combined with intracavity frequency doubling schemes have further led to efficient laser operation in the red to yellow-green spectral region [4,5]. Now, in this paper we present, to the best of our knowledge, the first intracavity generated Raman laser based on the fundamental wavelength of the three level neodymium transition at 908 nm in Nd:$YLiF_4$ (Nd:YLF), a challenging transition to oscillate due to the considerable reabsorption [6, 7]. A 1st Stokes laser emission at 990 nm with a peak output power of 0.88 W was demonstrated using stimulated Raman scattering (SRS) in KGW. An additional emission line at 976, corresponding to the 768 cm^{-1} Stokes shift in KGW is also demonstrated. This novel result will pave the way for high performance blue laser sources using intracavity frequency doubling schemes.

2. Fundamental laser operation at 908 nm

During a first experiment, the Nd(0.7 mol%):YLF crystals with lengths of 3, 6 and 9 mm were tested, a schematic of the cavity is given in Fig. 1a.

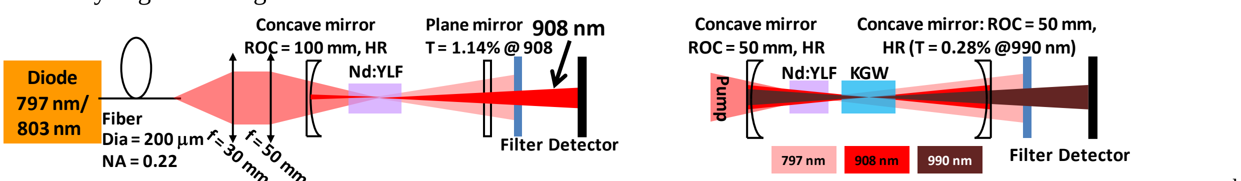

Fig. 1. Schematic representation of the setup used to generate a) fundamental laser emission, and b) Raman laser emission using a KGW crystal.

The laser was pumped at 797 nm and also at 803 nm. The performance of the laser is displayed in Fig. 2. The highest laser power was achieved using the 6 mm long crystal under 797 nm pumping, providing a maximum output power of 7.7 W at a launched pump power of 53 W (33 W of absorbed pump power). The observed "rollover" of the laser emission at large pump intensities is explained by the increased spectral width and spectral shift of the pump diode at these powers. Based on its performance, the 6 mm long Nd:YLF crystal was selected to carry out the Raman laser experiments.

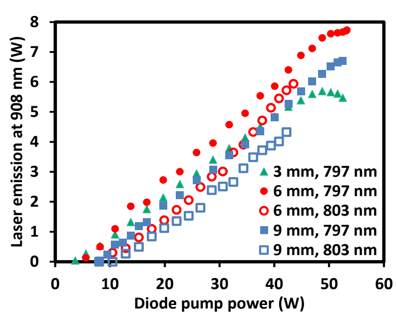

Fig. 2. Laser performance at 908 nm of three different crystals (3 mm, 6 mm and 9 mm length) at pump wavelengths of 797 nm and 803 nm.

3. Raman laser performance at 990 nm and 976 nm

KGW crystals with 5 and 10 mm length were introduced inside the cavity (see Fig 1 b), to initiate stimulated Raman scattering (SRS). The best Raman laser performance was found using the 10 mm long KGW crystal. Laser emission commenced at an absorbed pump power of 5.4 W, again the “rollover” was observed at the maximum output power of 0.88 W. About 0.5 W of output power was achieved using the smaller, 5 mm long KGW crystal. However damage to the surface of the Nd:YLF crystal occurred after a few seconds of operation. We believe that the defect was caused by the reduced conversion efficiency of the shorter KGW crystal resulting in a too-intense fundamental field. To prevent further damage, the experiment was repeated having the position of the Nd:YLF crystal closer to the mirror, thereby having a larger laser mode diameter at the crystal surface and reducing the laser efficiency, as can be seen in Fig. 3. The experimentally obtained data was analyzed using a steady-state rate equation model adapted from [8]. The model indicated an intracavity loss of about 2% in our laser and predicts improved laser output power at larger outcoupling efficiencies. During the experiments blue fluorescence inside the KGW crystal has been observed upon Raman laser oscillation. The observed fluorescence is attributed to crystal impurities [9]. Rotation of the Raman crystal by 90° around the optical axis changed the emission line from 990 nm to 976 nm (see Fig. 3b). However, the output power was very small due to the low output transmission of the mirror (T < 0.01%).

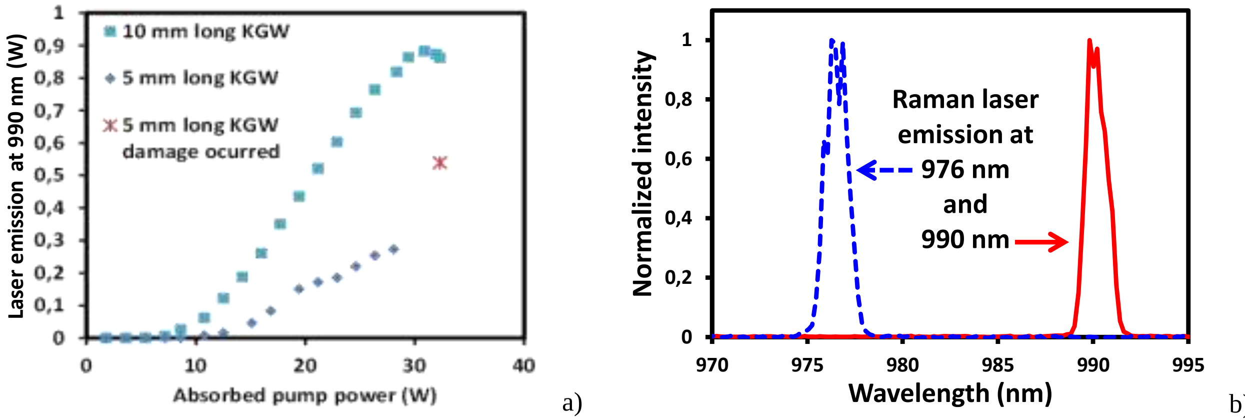

Fig. 3. a) Laser performance of the Raman laser at 990 nm for 2 different KGW crystal lengths. b) Observed normalized Stokes emission spectra.

4. Conclusions and discussion

Here we report, to the best of our knowledge, the first intracavity Raman laser that is generated using a quasi-three-level neodymium laser. When compared to four-level operation in a very similar set-up of Nd:YLF-KGW [5], the three-level laser generated 1st Stokes signal is approximately three times weaker at 21 W of absorbed pump power. Using this Nd:YLF-KGW laser scheme we demonstrate a maximum output power of 7.7 W at 908 nm and 0.88 W at 990 nm. Similar output powers are expected at 976 nm using optimized outcoupling efficiencies [5]. Given that the newly obtained wavelengths in the 900 – 1000 nm region can easily be converted to the blue wavelength region, using traditional sum-frequency (SFG) and second harmonic generation (SHG) [10]. These results will initiate a series of developments in the area of high intensity blue lasers at new, blue wavelengths.

Acknowledgement: This research project is financially supported by CNPq: 401580/2012 and FAPESP: 11437-8.

4. References

[1] T. T. Basiev and R. C. Powell, “Special issue on solid state Raman lasers - Introduction” Opt. Mater. **11**, 301-306 (1999).

[2] H. M. Pask, “The design and operation of solid-state Raman lasers,” Prog. Quant. Electron. **27**, 3-56 (2003).

[3] H. M. Pask, “Continuous-wave, all-solid-state, intracavity Raman laser,” Opt. Lett. **30**, 2454-2456 (2005).

[4] A. J. Lee, H.M. Pask, J. A. Piper, H. Zhang and J. Wang, “An intracavity, frequency-doubled BaWO Raman laser generating multi-watt continuous-wave, yellow emission,” Opt. Express **18**, 5984-5992 (2010)

[5] J. Jakutis-Neto, J. Lin, N. U. Wetter, H. Pask, “Continuous-wave Watt-level Nd:YLiF/KGW Raman laser operating at near-IR, yellow and lime-green wavelengths,” Opt. Express **20**, 9841–9850 (2012).

[6] W. Liang, X. H. Zhang, Z. L. Liang, Y. Q. Liu, Z. Liang, “Efficient continuous-wave 908 nm Nd:YLiF laser emission under direct 880 nm pumping,” Laser Phys. **21**, 320-322 (2011).

[7] S. Spiekermann, F. Laurell, “Continuous wave and Q-switched operation of diode pumped quasi-three level Nd:YLiF Lasers,” in Advanced Solid-State Photonics (ASSP), (2000).

[8] D. J. Spence, P. Dekker, H. M. Pask, “Modeling of continuous wave intracavity Raman lasers,” IEEE J. Sel. Top. Quant., **13**, 756-763

[9] Paper submitted to *Optical Materials Express*, December 2013.

[10] J. Jakutis-Neto, F. de Almeida Camargo, N. U. Wetter, “Deep blue Nd:LiYF4 laser in quasi-continuous and continuous operation,” in Advanced Solid-State Photonics (ASSP), San Diego, California, ATuA12, (2010).