Optoelectronics Research Centre
University of Southampton

Southampton SO17 1BJ, UK
Telephone: +44 1703 593150
e-mail: light@orc.soton.ac.uk

Efficient Room Temperature CW Yb:Glass Laser Pumped by a 946nm Nd:YAG Laser

R.Koch, W.A.Clarkson, D.C.Hanna, S.Jiang, M.J.Myers*, D.Rhonehouse*, S.J.Hamlin*, U.Griebner†, H.Schonnagel†*

*Kigre Inc., 100 Marshland Road, Hilton Head Island, SC 29926, USA
†Max-Born-Institut fur Nichtlineare Optik und Kurzzeitspektroskopie, Rudower Chaussee 6, D-12489 Berlin, Germany

Abstract

By pumping with a cw diode-pumped Nd:YAG laser operating at 946nm laser operation of a new Yb-doped phosphate glass with 440mW cw output power and a slope efficiency of 48% with respect to the absorbed pump power was achieved at room temperature.

Introduction

Ytterbium-based lasers have attracted increasing interest over the last few years. Efficient laser action has been demonstrated in Yb:YAG [1,2] and several other Yb-doped crystals [3]. Among its advantages are the small quantum defect (resulting in a low heat generation per excited ion), the simple electronic structure (avoiding such unwanted processes as excited state absorption, upconversion, and concentration quenching), the long fluorescence lifetime (in particular advantageous for Q-switched lasers) and the broad absorption and emission bandwidths. The latter is even more pronounced for glass host materials, making these materials particularly attractive for broadly tunable laser sources and for the generation of ultrashort laser pulses. Yb-doped silica fiber lasers have been investigated in detail, see Ref. [4] for a review. The problems relating to Yb-doped laser materials are its quasi-three-level character and the relatively small cross-section for stimulated emission compared to Nd-doped materials. The high pump intensity therefore required for effective operation results in a high thermal load per unit volume despite the small quantum defect. Thus a bulk cw Yb:glass laser operating at room temperature (using a Ti:sapphire pump laser and an experimental Yb-doped fluoride phosphate glass) has been reported only recently [5].

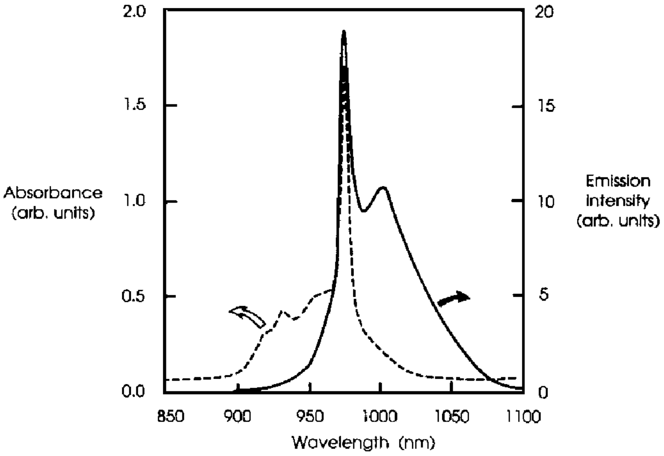
In this paper we present effective laser performance of a new ytterbium doped phosphate glass composition producing the highest cw output power so far for an all-solid-state Yb:glass laser system at room temperature.

Properties of QX/Yb:phosphate glass

The new glass, designated QX/Yb, is already commercially available. QX laser glasses have demonstrated significant enhancement in thermal loading capabilities over conventional phosphate-based laser glasses. This is mainly due to a relatively low thermal expansion coefficient of 8.3×10^{-6}/K (25-100°C) [6] which is smaller than for most common phosphate laser glasses. In addition, QX-based glasses are capable of being chemically strengthened via an ion exchange process. This process can increase fracture strength by a factor of three over unstrengthened material thus obtaining a modulus of fracture of greater than 50000 psi. Average output powers of greater than 110 W have been produced from QX/Nd at 1054 nm, and over 15W from QX/Er at 1540 nm in lamp pumped configurations [7,8].

In addition to its superior thermo-mechanical properties, QX/Yb also demonstrates excellent thermo-optical properties. QX/Yb exhibits a low thermal coefficient of optical path length due to its negative temperature coefficient of refractive index and low thermal expansion coefficient [6] and thus shows reduced thermal lensing.

Fig. 1. Absorption and emission spectra of QX/Yb phosphate glass.



The QX/Yb phosphate glass exhibits a fluorescence lifetime of approximately 2 ms for doping with 5 wt% Yb_2O_3. Fig. 1 shows the absorption and emission spectra. The absorption cross-section at 946nm is ~0.2×10^{-20} cm^2 and the maximum cross-section for stimulated emission (at ~975nm) is 0.7×10^{-20} cm^2. The Yb:phosphate glass spectra are much smoother with less structure than those for Yb:YAG, a promising feature for tunable operation and generation of ultrashort laser pulses.

Experimental results and discussion

A diode-pumped Nd:YAG laser operating at 946nm was used for longitudinal pumping of the Yb:glass sample in the form of a rod of 2mm diameter and 4mm length. This laser was end-pumped by a 20W diode bar using the beam-shaping technique described in Ref. [9]. The 946nm laser produced a stable cw-output of 2.6W with good beam quality ($M^2 < 2$). A high beam quality is essential for obtaining the high pump intensity required for efficient pumping of the quasi-three-level transition in Yb^{3+}. The output of the pump laser was focused into the QX/Yb sample by a lens with a focal length of 38mm resulting in a $1/e^2$ intensity spot radius of ~40µm. Due to the losses of the components in the pumping scheme only slightly more than 2W of pump power reached the sample.

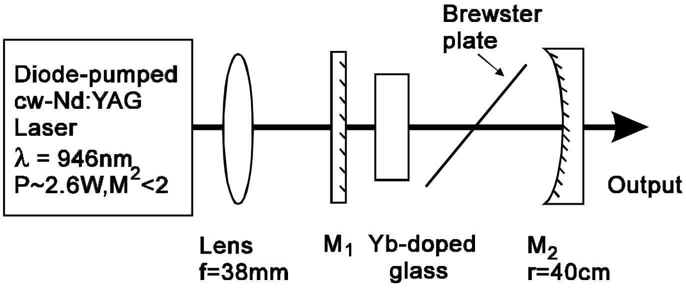


Fig. 2. Experimental scheme of the cw Yb:glass laser.

We chose a nearly hemispherical cavity with a radius of curvature of the output mirror of 400mm. This rather long cavity was chosen to enable the later insertion of any additional optical components required, such as, for these experiments, Brewster plate polarizers. The plane incoupling mirror was highly transmissive for the pump wavelength and HR-coated for the lasing wavelengths. The two different outcoupling mirrors used had transmissions of ~3% or ~6% in the range between 1000 nm and 1100 nm. The experimental scheme is depicted in Fig. 2.

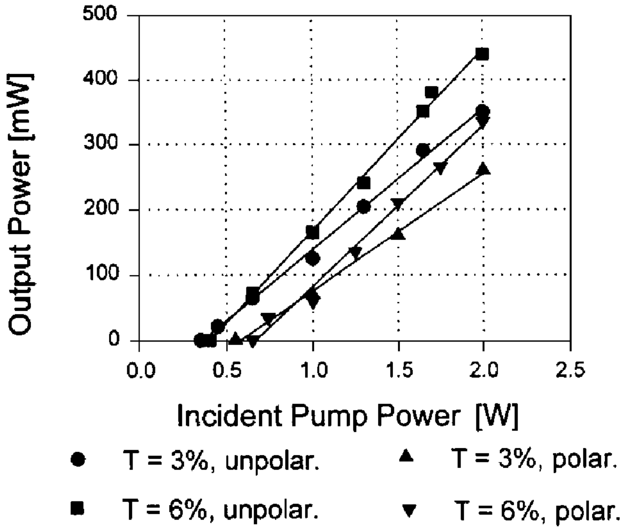


Fig. 3. Unpolarised and linear polarized output power versus incident pump power.

Fig. 3 shows the output power as a function of the incident pump power for unpolarized and linear polarized outputs. A linearly polarized output was selected by inserting a thin Brewster plate close to the sample. The highest output powers were obtained for the 6% output coupler, giving 440mW (unpolarized) and 335mW (linearly polarized) for 2W incident pump power. The temperature of the sample mount was kept constant at 15°C using a thermoelectric cooler. The slope efficiencies are ~28% (unpolarized) and ~25% (polarized). Taking into account the measured 38% single-pass absorption and the 80% reflection of the outcoupling mirrors at the pump wavelength, we estimate that ~57% of the incident pump power was absorbed in the sample with the Brewster plate absent and ~47% with Brewster plate present. The latter value is smaller since there is a reflection loss at the Brewster plate for the unpolarized pump beam that is not absorbed in the first pass of the laser rod. This is the main factor leading to an increase in threshold for the polarized laser compared to the unpolarized laser with an additional but smaller factor due to the stress-induced birefringence loss alone. A further feature contributing to the higher threshold is the larger mode area due to astigmatism induced by the Brewster plate. This can be significant in the nearly hemisperical cavity used in our experiment since it is at the edge of the stability range and thus only a small change in the effective optical length of the cavity can significantly influence the laser mode size and hence the threshold [10].

Using the estimated ratio for the absorbed pump power the slope efficiency with respect to the absorbed pump power is ~48% for the unpolarized laser. The laser emission was centred at 1032nm, and had a measured spectral bandwidth of ~4nm. This broad bandwidth suggests the potential for significant tuning although no attempt of tuning was made.

Conclusions

We have demonstrated what we believe to be the highest cw output power obtained so far for an-all-solid state bulk Yb:glass laser system at room temperature. With its excellent thermal characteristics, QX/Yb phosphate glass should be amenable to pumping directly by diode lasers. That would provide an attractive all-solid-state laser source with the prospect of broadly tunable cw output in excess of 1W, and should also be very promising for the generation of ultrashort laser pulses.

Acknowledgements

R. Koch was on leave from the Max-Born-Institut, Berlin, and was supported on a grant from the Deutscher Akademischer Austauschdienst. He is now with Jenoptik Laser, Optik, Systeme GmbH, Jena. This work was supported by the Bundesministerium fur Bildung, Wissenschaft, Forschung und Technologie under contract no. 13 N 6356 and by the Engineering and Physical Sciences Research Council. The preparation of the sample by B. Nippe from the Institut fur Kristallzuchtung, Berlin, is greatly acknowledged.

References

1. T.Y. Fan, S. Klunk and F. Henein, Optics Lett. 18 (1993) 423.

2. U. Brauch, A. Giesen, M. Karszewski, Chr. Stewen and A. Voss, Optics Lett. 20 (1995) 713.

3. L.D. Deloach, S.A. Payne, L.L. Chase, L.K. Smith, L.K. Wayne and W.F. Krupke, IEEE J. Quantum Electron. QE-29(1993) 1179.

4. H.M.Pask, R.J.Carman, D.C.Hanna, A.C.Tropper, C.J.Mackechnie, P.R.Barber and J.M.Dawes, IEEE J. Selected Topics in Quantum Electron 1 (1995) 2.

5. E.Mix, E.Heumann, G.Huber, D.Ehrt and W.Seeber, OSA Proc. on Advanced Solid-State Lasers, Vol. 24, eds. B.H.T.Chai and S.A.Payne (Optical Society of America, Washington, D.C., 1995) p. 339.

6. Data sheet 'QX laser glasses', Kigre Inc., 1996.

7. S.Jiang, J.D.Myers, R.Wu, G.M.Bishop, M.J.Myers and S.J.Hamlin, SPIE Proc. Vol. 2379 (1995) 17.

8. S.Jiang, J.D.Myers, D.L.Rhonehouse, G.M.Bishop, M.J.Myers and S.J.Hamlin, in: Conf. on Lasers and Electro-Optics, Vol. 15 (1995) OSA Tech. Dig. Series (Optical Society of America, Washington, D.C., 1995) p. 17.

9. W.A.Clarlison, R.Koch and D.C.Hanna, Optics Lett. 21 (1996) 737.

10. W.P.Risk and W.Lenth, Optics Lett. 12 (1987) 993.