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Laser performance of a new ytterbium doped phosphate laser glass

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Abstract

Laser operation of a new Yb-doped phosphate glass with 440 mW cw output power and a slope efficiency of 49% with respect to the absorbed pump power was achieved at room temperature by pumping with a cw diode-pumped Nd:YAG laser operating at 946 nm.

Key Words

Infrared and far-infrared lasers, Rare earth doped materials, Glass and other amorphous materials, Laser materials

Introduction

Ytterbium based lasers have attracted much attention due to their low heat generation, simple electronic structure (absence of unwanted processes such as excited state absorption and concentration quenching) and broad absorption and emission bandwidths. The inherently small quantum defect in Yb^{3+} lasers is a motivating interest for operation at higher power levels. Efficient laser action has been demonstrated in Yb:YAG [1,2] and several other Yb-doped crystals [3]. There is also much interest in Yb^{3+} in glass host materials. Yb-doped silica fiber lasers have been investigated in detail in [4]. Laser properties of ytterbium in fluoride phosphate glasses and efficient cw laser operation at room temperature using a Ti:sapphire pump laser are reported in [5].

In this paper we present laser performance of a new ytterbium doped phosphate glass composition, designated QX/Yb. QX laser glasses have demonstrated significant enhancement in thermal loading capabilities over conventional phosphate based laser glasses. Average output powers of greater than 110 W have been produced from QX/Nd at 1054 nm, and 7 W from QX/Er at 1540 nm in lamp pumped configurations. More recent data has proven that over 15 W may be extracted from lamp pumped QX/Er at 1540 nm [6,7]. The QX/Yb phosphate glass exhibits a fluorescence lifetime of approximately 2 ms for doping with 5 wt% Yb_2O_3. Figures 1(a) and 1(b) show the absorption and emission spectra. The absorption cross-section at 946 nm is ~ 0.2 x $10^{-20}cm^2$ and the maximum cross-section for the stimulated emission is ~ 0.7 x $10^{-20}cm^2$. The Yb:phosphate glass spectra are much smoother than those for Yb:YAG.

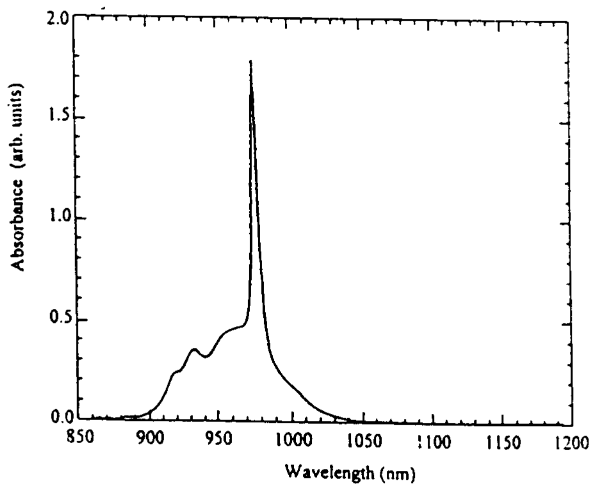

Figure 1 (a). Absorption spectrum of QX/Yb phosphate glass

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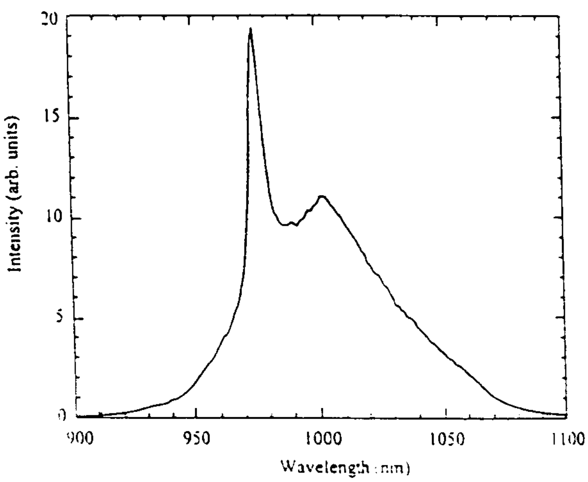

Figure 1 (b). Emission spectrum of QX/Yb phosphate glass

Laser experiments

Longitudinal pumping

A diode pumped Nd:YAG laser operating at 946 nm was used for longitudinal pumping of the Yb:glass sample. This laser was end-pumped by a 20 W diode bar (Opto Power Corporation OPC-A020-mmm-CS) using the two-mirror beam-shaping technique and was very similar to that described in detail in [8]. The 946nm laser produced a stable cw-output of 2.6 W 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 laser was focused into the 4 mm thick QX/Yb sample by a lens with a focal length of 38 mm resulting in a $1/e^2$ intensity spot radius of ~ 40 µm. Due to the losses of the components in the pumping scheme only slightly more than 2W of pump power could reach the sample. The maximum pump intensity of ~ 40 $kWcm^{-2}$ is in the order of the saturation intensity for the Yb:glass at the pump wavelength.

We chose a nearly hemispherical cavity with a radius of the outcoupling mirror of 400 mm. This rather long cavity provides a region of low beam divergence close to the sample which is essential for proper operation of Brewster plate polarizers and birefringent filters [9]. 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 a transmission of ~ 3% or ~ 6%, respectively, in the range between 1000 nm and 1100nm. Taking into account the ~ 80% reflection of the outcoupling mirrors at the pumpwavelength, we estimated that ~58% of the incident pump power was absorbed in the sample. The residual pump beam was blocked with a suitable external mirror having high reflectivity for the pump wavelength and high transmission for wavelengths >1µm. The laser spectrum was analyzed using an optical spectrum anlyzer (ANRITSU MS 9001 A). Fig.2 shows the output power as a function of the incident pump power for the different mirror transmissions of 3% and 6%. The performance characteristics for an Yb:YAG crystal with 5% doping and a length of 3 mm (~ 60% of pump power absorbed in double pass) are shown for comparison. The highest output powers were obtained for the 6% output coupling mirror with 440 mW (QX/Yb) and 870 mW (Yb:YAG) for 2 W incident pump power. The overall slope efficiency for the 6% mirror transmission is ~28% (QX/Yb) and ~45% (Yb:YAG). The temperature of the sample mount was kept constant at 15°C using a thermoelectric cooler. By reducing the mount temperature to 7°C an enhancement of the output power by ~10% could be obtained in all cases.

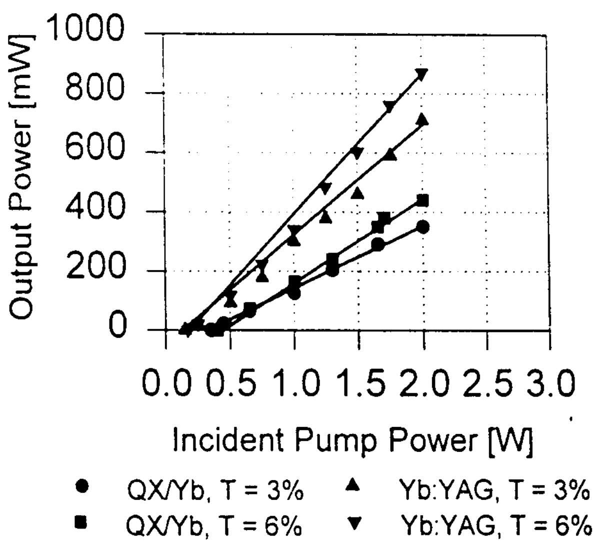

Figure 2. Output power versus input power for QX/Yb and Yb:YAG

Fig. 3 shows the dependence of the output power for QX/Yb on absorbed pump power for both mirror transmissions for unpolarized and linear polarized output. A linear polarized output was selected by simply inserting a thin Brewster plate close to the sample. The best results were obtained again for the outcoupling mirror with ~6% transmission. The slope efficiency with respect to absorbed power is ~49% (unpolarized) and ~46% (linearly polarized). This slope efficiency of 49% corresponds to the theoretical value that can be expected assuming losses (fixed cavity loss and partially saturated reabsorption loss) of 3 - 5% as estimated from a knowledge of the threshold and the circulating laser intensity in the sample which is in the order of 100 kWcm^{-2}.

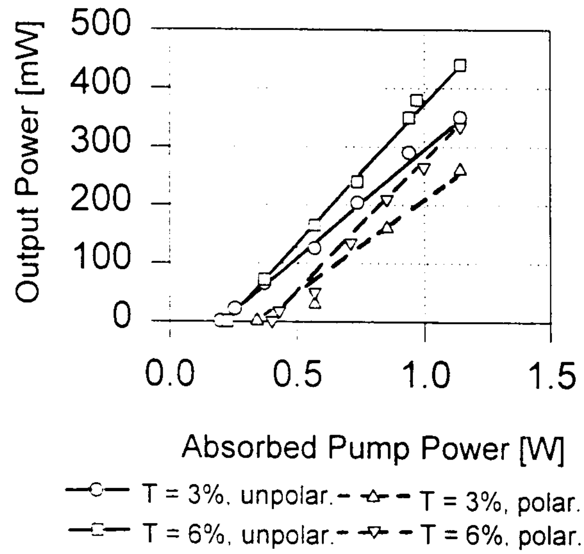

Figure 3. Unpolarized and linear polarized output power versus input power absorbed in QX/Yb

The ratio of maximum polarized output power (335 mW) to unpolarized output is ~76% compared to the measured corresponding value for Yb:YAG of 82% (no graph shown). This indicates that despite cw pumping, problems regarding thermal loading and resulting stress induced birefringence are comparable to those for Yb:YAG. The heat dissipation of ~2W/cm is fairly well tolerated. The measured M^2 value of ~2.5 for the highest output powers of the QX/Yb laser could be improved further by optimization of the cavity design.

The spectral bandwidth was typically ~ 4 nm with the line centre around 1032 nm. No particular attempts to achieve tunable laser operation by using birefringent filters [9] were made.

Transversal pumping

With a QX Yb phosphate glass sample with 15 wt% Yb_2O_3 laser operation has been demonstrated in another experiment in the wavelength range from 1025 nm to 1060 nm with spectral widths of 1.0 to 3.0 nm (FWHM). The sample was side pumped by a single quasi-cw diode bar (SDL-6321-A1) with a peak power of 60 W at 975 nm (wavelength of the absorption peak of the QX/Yb glass). In order to achieve the required pump power density a line focus was formed within the sample using a suitable combination of lenses. A nearly hemispherical resonator with a 50 mm radius output coupler with ~3% transmission between 1000 nm and 1100 nm was used in this experiment. The flat HR-coated back mirror was in contact with the 4 mm long sample. The laser wavelength that is actually emitted, is strongly influenced by the wavelength-dependent reabsorption. This is particularly the case for this heavily doped sample. Of particular importance in determining the emitted wavelength is the difference between gain (reduced by fixed cavity losses) and reabsorption loss. For a given inversion distribution the lasing wavelength could be tuned by adjusting the resonator length and hence the laser mode size. Laser operation was obtained over a tuning range between 1036 nm and 1055 nm (Fig.4). These observations and explanations are presented in detail in [10].

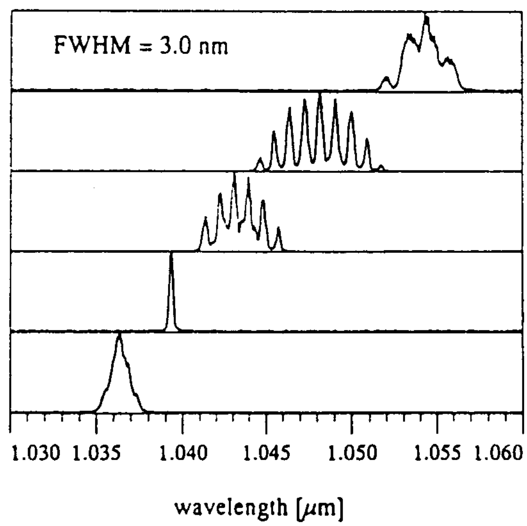

Figure 4. Emission spectra of the QX/Yb phosphate glass laser in dependence on the mode volume (decreasing resonator length and hence increasing mode volume from the bottom to the top)

Conclusion

We have demonstrated what we believe to be the highest cw output power obtained so far for an all-solid-state Yb:glass laser system at room temperature and the first laser operation of side pumped Yb:glass using quasi-cw diode bars. Due to its excellent thermal characteristics, QX Yb phosphate glass could be pumped directly by diode-lasers with the prospect of broadly tunable cw output powers in excess of 1 W, and additionally should be attractive for the generation of ultrashort laser pulses.

Acknowledgments

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