Diode-Pumped, Self-Frequency Doubled Red Nd:YCOB Laser

Qing Ye, Lawrence Shah, Jason M. Eichenholz[1], Dennis A. Hammons, Robert E. Peale, Martin Richardson[1], Bruce H.T. Chai[2]
CREOL, University of Central Florida, 4000 Central Florida Blvd., Orlando, FL 32816
Tel: (407) 823-6838, Fax: (407) 823-6880
Ye@creol.ucf.edu

[1]*Also Laser Energetics, Inc., 4044 Quaker Bridge Road, Mercerville, NJ 08619*
[2]*Also Crystal Photonics, Inc., 2729 North Financial Court, Sanford, FL 32773*

Aland Chin
Polaroid Corporation, 1 Upland Road, Norwood, MA 01062

Abstract: The first diode-pumped cw red laser through self-frequency doubling is demonstrated in 5% Nd:YCOB crystal cut along phase matching direction. 13.5 mW red output at 666 nm has been generated with 950 mW diode pump power absorbed in the crystal.
OCIS codes: (190.2620) Frequency conversion; (140.3480) Lasers, diode-pumped

Introduction

Diode-pumped visible cw laser sources are playing a very important role in a variety of applications in the entertainment, industrial and medical markets, due to their high efficiency and compactness. The realization of red, green, and blue (RGB) lasing from diode-pumped self-frequency doubling and thereafter the combination of the three colors have even greater potentials in the entertainment market, especially for full color displays. Diode-pumped, self-frequency doubling lasers, have the advantages of a simpler design and a lower cost compared to conventional diode-pumped intra-cavity frequency doubled lasers using crystals such as Nd:YVO_4 plus KTP [1]. In order to achieve self-frequency doubling, the crystal must have both good laser performance and harmonic generation properties. The material Nd:$YCa_4O(BO_3)_3$ (Nd:YCOB) is a promising candidate which appears to have the ideal properties for self-frequency doubling action [2].

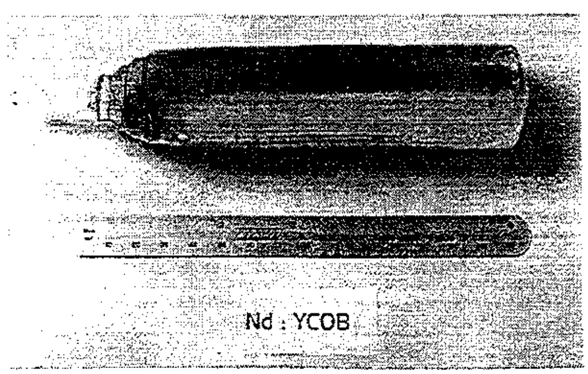

Fig. 1. Picture of 5% Nd:YCOB crystal.

The YCOB crystal is one of the rare-earth calcium oxyborate compounds with space group Cm. Single crystals of 40 mm in diameter and 150 mm in length (Fig. 1) with high optical quality can be pulled directly from a nearly congruent melt in about 6 days [3]. The distribution coefficient for neodymium in YCOB crystal is near unity. This permits high concentration doping of neodymium into the YCOB host while the homogeneity inside crystal still maintains. The concentration quenching of Nd^{3+} luminescence is relatively weak. The fluorescence lifetime at 1060 nm of 2%, 5% and 10% Nd:YCOB were measured to be 102 μs, 100 μs, and 96 μs respectively.

Spectroscopic Characterization

The absorption and emission spectrum of Nd:YCOB are both polarization dependent. The maximum absorption occurs for light polarized along Z-axis (Fig. 2). Several strong absorption peaks in the vicinity of 800 nm make this material ideal for laser diode pumping. The polarized emission spectrum of 5% Nd:YCOB indicates several peaks corresponding to the three common transitions of Nd^{3+} ion (Fig. 3). The strongest emission of the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ transition is at 1060 nm for polarization parallel to the Z-axis. This wavelength can be self-frequency doubled to 530 nm to generate green light. The strongest emission of the $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transition is at 1332 nm, also polarized parallel to the Z-axis. By cutting the crystal along the phase matching direction at this wavelength, the 1332 nm fundamental emission can be self-frequency doubled to generate the red light at 666 nm. The emission corresponding to the transition of the $^4F_{3/2} \rightarrow {}^4I_{9/2}$ is much weaker compared to the emissions at 1.06 and 1.3 μm. It has several peaks, with the sharpest one polarized parallel to the Y-axis at 936 nm. If lasing can be achieved at 936 nm, self-frequency doubling will generate blue light at 468 nm.

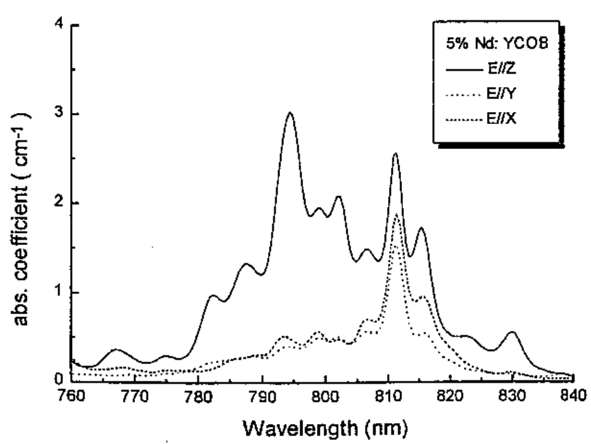

Fig. 2 The absorption spectrum of 5% Nd:YCOB for light polarized parallel to the X, Y, Z axes.

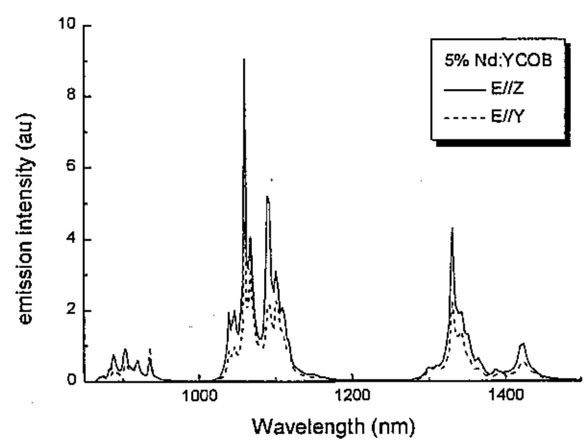

Fig. 3. The emission spectrum of 5% Nd:YCOB for light polarized parallel to the Y, Z axes.

Experimental Results

We reported 62 mW of green emission at 530 nm in 5% Nd:YCOB before, with one watt diode pump power absorbed [4]. The similar cavity was utilized to generate red lasing through self-frequency doubling. A simple hemispherical laser resonator consisted of a flat mirror with high reflection at 1332 and 666 nm, and a 10-cm radius of curvature output coupler with high transmission at 666 nm (T~95%) and high reflection at 1332 nm (R~99.6%). To suppress the strong emission at 1 μm, both mirrors had more than 20% loss at 1060 nm. The 4x4x6 mm^3, 5% Nd:YCOB crystals were cut along type-I phase matching direction in XY plane at an angle of 28° from X-axis. Both surfaces were coated with a triple-band anti-reflection coating at all three wavelengths, 1332, 666 and 812 nm (Quality Thin Films TBAR). The crystal was placed next to the flat mirror and absorbed approximately 70% of the incident pump light at full diode current. The polarization of pump light was parallel to crystal's Z-axis and the pump was focused into the crystal through the flat mirror that was over 90% transparent at 812 nm.

The cw red laser powers as a function of absorbed pump power have been measured in two crystals as shown in Figure 4. A maximum of 13.5 mW red output at 666 nm has so far been measured with 950 mW diode pump power absorbed in the crystal. The lowest threshold obtained for red lasing was 270 mW. We believe this is the first time that cw red laser emission has been generated utilizing diode-pumped self-frequency doubling. The optimization of the cavity and crystal orientation should result in higher red power. With the red laser on, we also measured the fundamental output power at 1332 nm through an RG850 filter with a calibrated Ge detector (Fig. 5). Fundamental output power of over 50 mW leaked through the curved mirror with an output coupling of only 0.4% with 950 mW pump power absorbed.

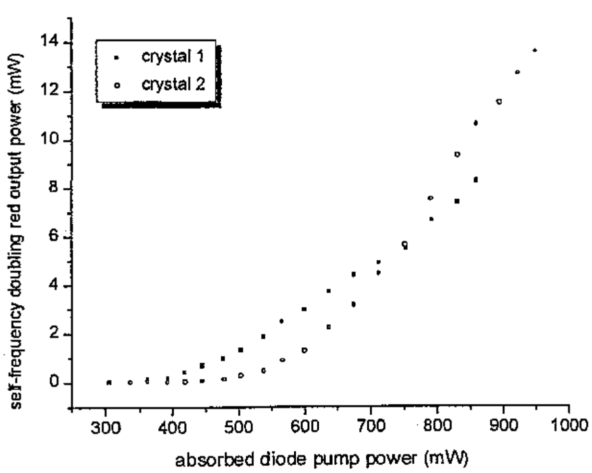

Fig. 4. The red output power at 666nm vs. the absorbed diode pump power.

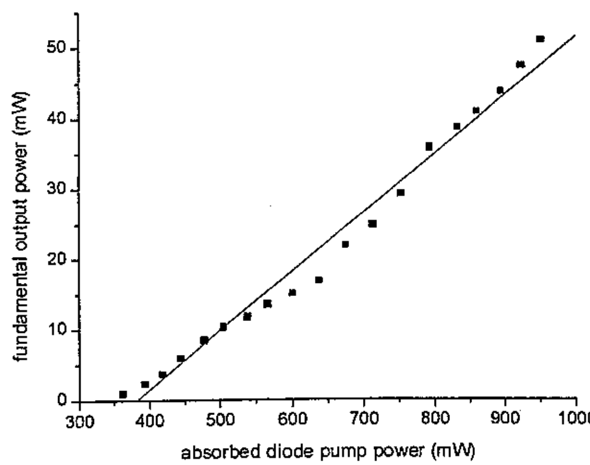

Fig. 5. The leaked fundamental output power at 1332 nm vs. the absorbed diode pump power.

Since the emission at 936 nm is much weaker than the emission at 1060 nm, higher suppression of the 1060 nm emission is needed in order to achieve the 936 nm lasing. The development of a laser system which incorporates self-frequency doubling of the 936 nm laser emission is currently under investigation and experiments now in progress will be reported later.

Summary

We have successfully demonstrated two of the three colors needed to obtain RGB lasing by self-frequency doubling. The diode-pumped cw red lasing by self-frequency doubling in Nd:YCOB crystal is reported for the first time, as far as we know. An output of 13.5 mW at 666 nm was obtained with less than 1 W pump power absorbed. These results are promising. We believe further optimization of the cavity and crystal orientation will result in higher red powers.

Acknowledgements

The authors would like to thank J. Tawney, N. Vanasse and A. Rapaport for their invaluable support.

References

1. W. Wiechmann, L.Y. Liu, and S. Kubota, "Efficient 1 watt single frequency cw green generation from an intracavity-doubled diode-pumped Nd:YVO_4 laser," in *OSA proceedings on Advanced Solid State Lasers*, 24 96-97 (1995)
2. B.H.T. Chai, J.M. Eichenholz, Q. Ye, D.A. Hammons, W.K. Jang, L. Shah, G.M. Luntz, and M. Richardson, "Self-frequency doubled Nd:YCOB laser," *OSA Trends in Optics and Photonics on Advanced Solid State Lasers*, 19 56-58 (1998)
3. Q. Ye, B.H.T. Chai, "Crystal growth of $YCa_4O(BO_3)_3$ and its orientation" J. Crystal Growth, 197 228-235 (1999).
4. B.H.T. Chai, J.M. Eichenholz, Q. Ye, W.K. Jang, and M. Richardson, "Visible light generationby self-frequency doubling in Nd:YCOB," in Technical Digest of *Conference on Lasers and Electro-Optics* (Optical Society of America, San Francisco, CA, 1998) paper CThA6.