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Second harmonic generation in Yb doped $YCa_4O(BO_3)_3$

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Abstract

We report efficient second harmonic conversion in a new nonlinear optical crystal, Yb^{3+} doped $YCa_4O(BO_3)_3$, that is non-hygroscopic, has good optical and mechanical properties, and can be grown in large sizes. The effect of Yb concentration on the harmonic conversion efficiency is also investigated.

Second harmonic generation (SHG) of infrared laser radiation is widely used for the generation of coherent visible and UV radiation. To date, KH_2PO_4 (KDP), LiB_3O_4 (LBO), β-BaB_2O_4 (β-BBO), and $KTiOPO_4$ (KTP) have been used for SHG of Nd-type lasers [1]. However all these materials suffer from some sort of limitations, such as their maximum available size, hygroscopy, or low harmonic conversion efficiency. KDP, for instance, can be grown to large sizes, but is soluble in water, and has a small nonlinear coefficient and a small acceptance angle [2–6]. Although KTP has the highest nonlinear coefficient and a large angular bandwidth, it suffers from issues such as transmission losses, refractive index changes, and cannot be used with high energy lasers because it can only be grown to small sizes [7–10]. In the ultraviolet region, LBO and β-BBO are recognized as the most useful nonlinear optical crystals, but they are somewhat hygroscopic and also are difficult to grow to large dimensions. Despite the long history of harmonic generation, it is therefore not surprising that there is still room for new nonlinear optical crystals which mitigate these limitations.

In this paper we report the first measurements of second harmonic generation in Yb^{3+} doped YCOB. This material has a high effective nonlinear coefficient, and a high damage threshold. It is also non-hygroscopic, has good mechanical properties allowing easy optical polishing, and can be grown to large sizes (>40 mm, diameter). The replacement of Y with Yb in the lattice structure, induces a modification of electric field in the lattice structure, and potentially can lead to an improvement of its non-linear optical characteristics. In this paper we show this to be the case by investigating the changes in second harmonic conversion efficiency with Yb doping concentration.

YCOB is a negative biaxial crystal, whose three crystallographic axes a, b, and c are not mutually orthogonal. We therefore define indicatrix axes, X, Y and Z, with the Y axis consistent with b axis according to the convention of refractive indices, $n_X < n_Y < n_Z$, providing the orientation shown in Fig. 1. For type I phase matching conditions, the phase matching angle for 1064 nm radiation is 33.95° from the X axis [11–14].

The experiments on SHG in Yb:YCOB were performed with the output of a Q-switched single mode, Nd:YAG laser [15]. This laser produced 6 mJ pulses with a FWHM duration of 10 ns. The beam diameter was at the entrance to the SHG crystal reduced to 1 mm to provide peak incident power densities of 60 MW/cm^2. The second harmonic conversion efficiency of a number of Yb^{3+} doped YCOB crystals was measured over a range of input power conditions with a pair of calibrated fast (<1 ns) photodiodes monitoring the incident fundamental 1064 nm radiation and the frequency upconverted radiation.

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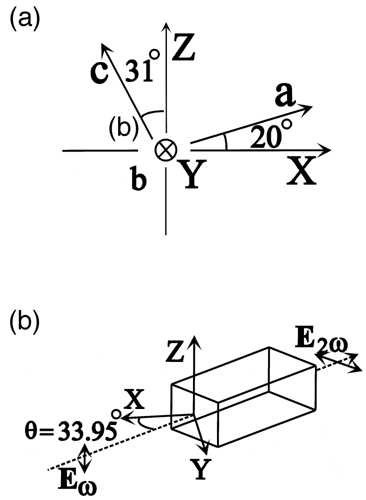

Fig. 1. (a) Crystal axes of YCOB (X, Y, Z: indicatrix axes, a, b, c: crystallographic axes), (b) type I phase matching configuration for SHG (1064 nm → 532 nm).

Fig. 2 shows the second harmonic conversion efficiency as a function of the fundamental intensity of Nd:YAG laser for two crystals, undoped YCOB and YCOB doped with 20% Yb. At high incident intensities the second harmonic conversion efficiency tends to saturate due to depletion of the fundamental laser light in the long crystal. The length of each crystal was 25 mm, and the electric field of the incident laser radiation was aligned parallel to the Y-axis. In the range of 10–60 MW/cm^2, the second harmonic conversion efficiency of 20% Yb:YCOB was increased by about 10–15% with respect to that of undoped YCOB.

We have measured this increase in the second harmonic conversion efficiency as a function of Yb doping concentration. The measured SHG conversion efficiencies for YCOB crystals doped with various Yb concentrations are shown in Fig. 3(a). For these crystals, the polarization of

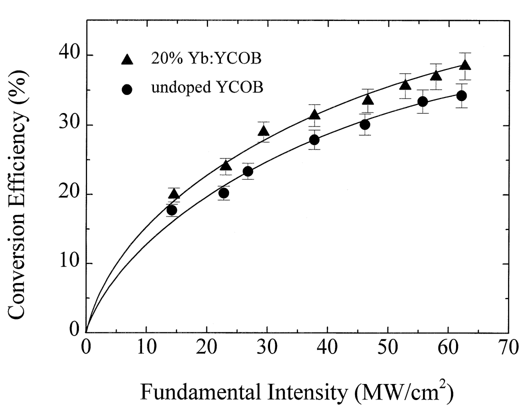

Fig. 2. Variation of second harmonic conversion efficiency with the fundamental intensity (crystal length: 25 mm, $E \| Y$).

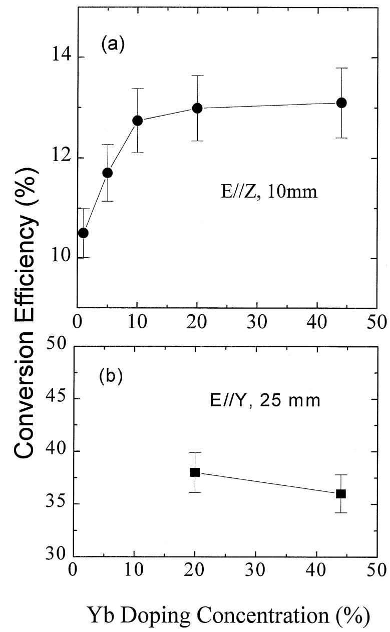

Fig. 3. Variation of second harmonic conversion efficiency with Yb doping concentration. (a) $E \| Z$, 10 mm, (b) $E \| Y$, 25 mm.

the incident fundamental radiation was oriented parallel to the Z-axis, and each crystal was only 10 mm long. Consequently the overall conversion efficiency was lower. In the range of 0–10% Yb doping concentration, the second harmonic conversion efficiency increased significantly. At higher concentrations up to 44%, it increased only slightly with Yb doping concentration. A similar improvement in SHG conversion efficiency was also found for Y-cut crystals. Fig. 3(b) shows the conversion efficiency for 25 mm long crystals with polarization of the fundamental laser radiation parallel to the Y-axis.

In summary, YCOB is a promising new nonlinear optical crystal. It has the attractive properties of good optical quality, a high damage threshold, is non-hygroscopic, and can be grown to large sizes with good mechanical properties which allow for easy optical polishing. Furthermore, we report an improvement of its optical nonlinearity by doping it with ytterbium. Its nonlinearity was improved by ~15% when doped with 20% ytterbium, the maximum second harmonic conversion efficiency appearing at this concentration.

In addition to possessing excellent qualities as a nonlinear optical crystal, the oxoborates are also good laser host materials, and therefore allow the development of efficient self-frequency doubled lasers [16]. Self-frequency doubling in Yb doped YCOB and in Nd doped YCOB were demonstrated in cw and pulsed lasers for the first time [17–19]. In the case of Yb:YCOB, its absorption bands near 900 nm provide with it ideal optical pumping with high power InGaAs diode lasers, and its broad emission band centered at 1060 nm should allow efficient tunable laser light generation in the green region of the spectrum.

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