Efficient second-harmonic generation of CW radiation in an external optical cavity using non-linear crystal BIBO

Sergey KOBTSEV*, Alexander ZAVYALOV

Novosibirsk State University, Laser Systems Laboratory, Pirogova 2, Novosibirsk, 630090, Russia;

ABSTRACT

Presented are the results of experimental investigations of a resonant doubler of CW radiation frequency that uses a novel non-linear optical crystal BIBO. For the first time by using this crystal in an external resonator a stable single-frequency generation of the second-harmonic radiation was achieved with the output power of 270 mW at the wavelength of 425 nm. Conversion efficiency is as high as 36%. Generation instabilities were observed at second harmonic power higher than 300 mW inside the doubler cavity.

Keywords: resonant frequency doubler, non-linear crystal BIBO, external optical cavity.

1. INTRODUCTION

Second harmonic generation (SHG) of CW single-frequency radiation in external resonant doubler is one of the most efficient techniques of frequency doubling of CW single-frequency laser. An obvious great advantage of this approved and perspective technology of SHG consists in the fact, that the laser, frequency of which is to be doubled, does not need any schematic/structural changes/additions. Nonlinear crystal is placed inside high-Q external optical cavity, the length of which is automatically controlled so that the laser frequency remains always at maximum of transmission peak of this cavity. Small losses in the external resonator containing minimal number of optical elements result in comparatively high intracavity power enhancement factor.

Enhancement factor of input radiation power achievable in the best external doubler are as much as 100-150 and even more, i.e., for example, when input radiation power is 1 W, the power inside the cavity of doubler can be higher than 100 W, what causes high-efficient radiation conversion in this method. Conversion coefficient γ, defined by the expression $P_{2\omega}=\gamma \times P_{\omega}^2$, where $P_{2\omega}$ – second harmonic power and P_{ω} – fundamental radiation power, can reach in this method the values of order (1-5) x 10^{-5}, and the absolute values of second harmonic power in the case of CW single-frequency radiation can be as much as hundreds of milliwatts and even several watts.

Note that high efficiency of this frequency doubling technique is achieved when input radiation power is greater than 0.5 – 1 W, whereas at input radiation powers less than 0.5 W conversion efficiency is relatively low. In this connection there is a great interest in new nonlinear crystals, which are prominent due to higher nonlinearity and their capacity to provide higher conversion efficiency in this method when input radiation power is relatively low and, perhaps, also at high input powers.

Recently developed non-linear bismuth triborate crystal BiB_3O_6 (BIBO) has already shown much prospect in various configurations for frequency doubling of both CW and pulsed radiation [1-5]. However, application of this crystal in a resonant doubler of CW radiation frequency has been hitherto studied in one publication only [6] where stable second-harmonic output was not achieved at powers higher than 115 mW because of high-magnitude fluctuations (up to 100%) in the output power of the second-harmonic radiation.

*kobtsev@lab.nsu.ru, phone/fax +7 383 339 72 24, www.nsu.ru/srd/lls/english/

Laser Optics 2006: Solid State Lasers and Nonlinear Frequency Conversion, edited by Vladimir I. Ustyugov,
Proc. of SPIE Vol. 6610, 66100P, (2007) · 0277-786X/07/$18 · doi: 10.1117/12.740016

2. EXPERIMENT

The scheme of used resonant doubler is given in Fig. 1. Ring cavity of doubler is formed by two spherical mirrors (R = 100 mm) and two plane ones. Fundamental radiation enters the cavity through one of plane mirrors with transmission of 1.7%. This transmission coefficient is optimal since it corresponds to the highest increment of input radiation power in the doubler cavity. Dichroic output mirror M4 had transmission 90% for the radiation of the second harmonic.

Locking the external resonator transmission peak to the frequency of the input radiation was done according to the polarisation technique of Hansch-Couillaud [7]. The length of the external resonator was controlled with the help of two PZT's, one of which was relatively slow (its bandwidth being 500 Hz) and could change the resonator length by up to 4.7 μm, whereas the second PZT was comparatively fast (its bandwidth being 0.5–80 kHz), however the resonator length adjustment was limited to 0.5 μm. A reliable lock system of the frequency doubler with the two control rings, fast and slow, allowed comfortable operation of the frequency doubler both under almost arbitrary external perturbations and with a pump laser without frequency stabilisation.

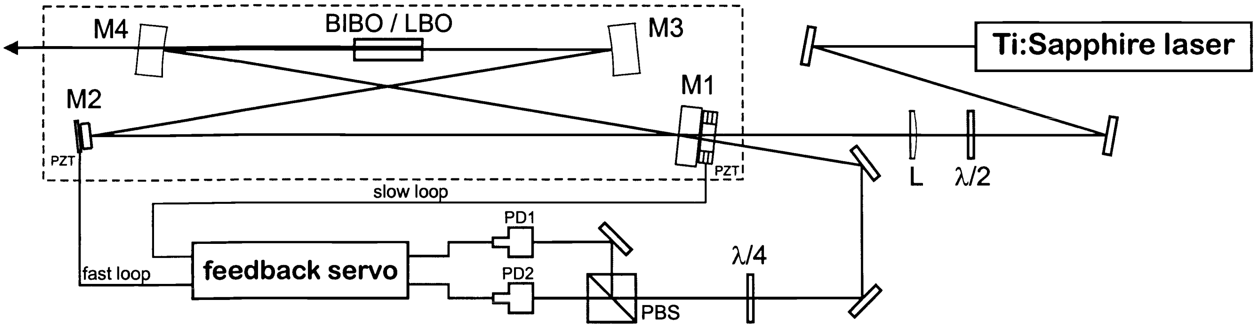

Fig. 1. Schematic diagram of the frequency doubler: M1-M4 - mirrors of the doubler cavity, PD1, PD2 - photodiodes, PBS - polarizing beam splitter, L - mode-matching lens, PZT - piezo-electric transducer.

In the experiments we used 6-mm-long nonlinear BIBO crystal produced by Foctek, as well as 15-mm-long LBO crystal. Both crystals have the orientation of work surfaces for normal beam incidence and these surfaces have antireflection coating. The cavity of doubler was optimized for LBO crystal, beam waist radius in which is about 40 um.

Fig. 2 shows the dependences of beam waist radius W_0 in used LBO and BIBO crystals on the distance between spherical mirrors. The maximum waist radius amounts 41 um and can be reduced to ~ 30 mcm thanks to the change of distance between spherical mirrors.

In Fig. 3 calculated Boyd-Kleinman parameters [8] for used nonlinear crystals are given as a function of beam waist radius W_0 for fundamental harmonic of radiation inside the crystal. As can be seen from these graphs, for LBO crystal Boyd-Kleinman parameter (which is proportional to the power of second harmonic) reaches the maximum at beam waist radius inside the crystal of 28 um, i.e. for this crystal the used cavity is close to optimal one. The maximum value of Boyd-Kleinman parameter for BIBO crystal is reached when the beam waist radius inside the crystal is about 17 um, i.e. BIBO crystal was used with beam waist radius that exceeds the optimal value.

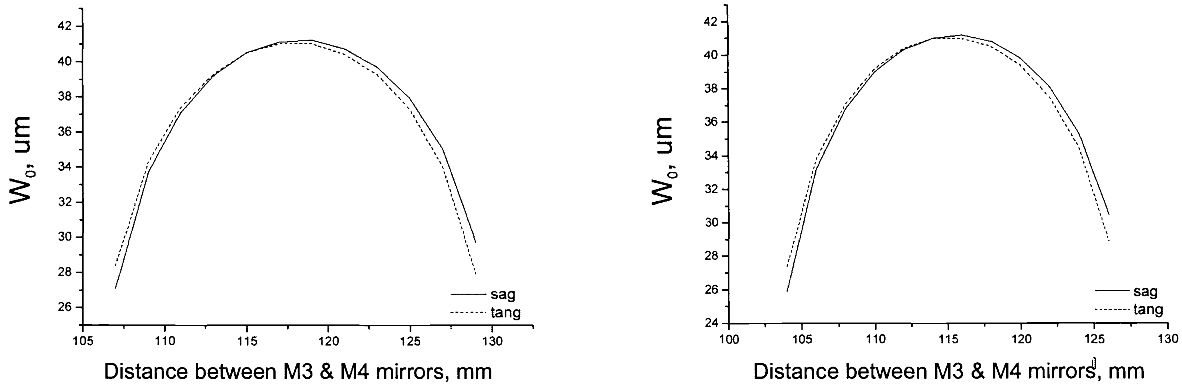

Fig. 2. Dependences of beam waist radius W0 in used LBO (left) and BIBO (right) crystals on the distance between spherical mirrors

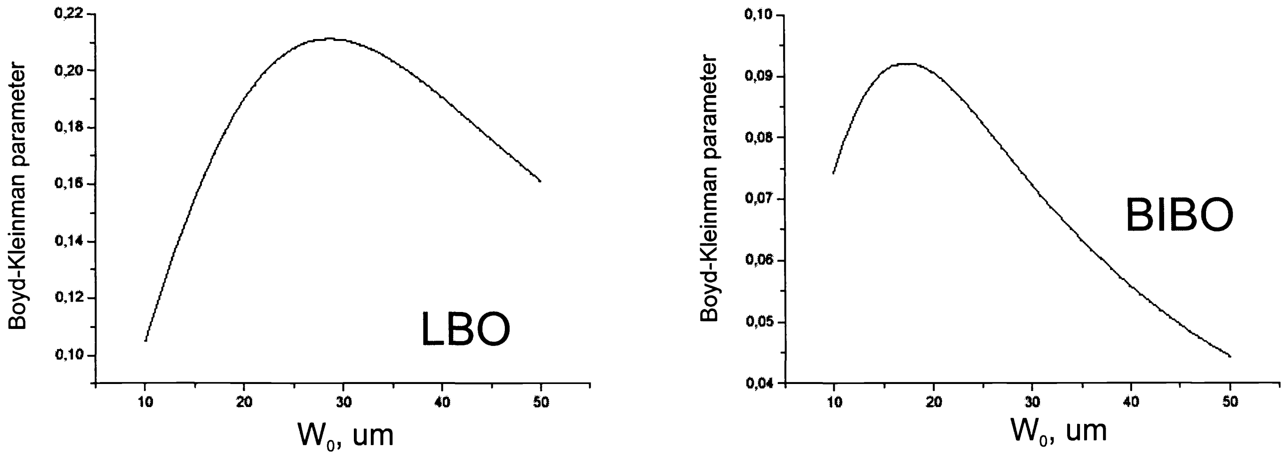

Fig. 3. Calculated Boyd-Kleinman parameters for used nonlinear crystals are given as a function of beam waist radius W0 for fundamental harmonic of radiation inside the crystal.

The quality of mode matching between the Ti:Sapphire pump laser and the frequency doubler resonator was quite high and was achieved with a single lens. In Fig. 4 the transmission spectrum of the external resonator is presented that was obtained by scanning the resonator length with a PZT-controlled mirror. The magnitude ratio of the main and side peaks exceeds 60 (see Fig. 4). As a result of the precise mode matching, high quality of the mirrors, and optimised transmission of mirror M1 the frequency doubler exhibits high intensity enhancement factor for the pump radiation inside the cavity. Without the non-linear crystal in the empty cavity this factor reached 130. Upon insertion of the non-linear crystal into the doubler cavity the power enhancement factor was somewhat lower and amounted to 100 for LBO and 123 BIBO crystals. It is necessary to note that these high power enhancement factors were observed under condition of slight ellipticity of the pumping beam typical of ring-cavity Ti:Sapphire lasers. In our experiment we used the TIS-SF-07 Ti:Sapphire laser by "Tekhnoscan Co." with output power 750 mW at 850 nm.

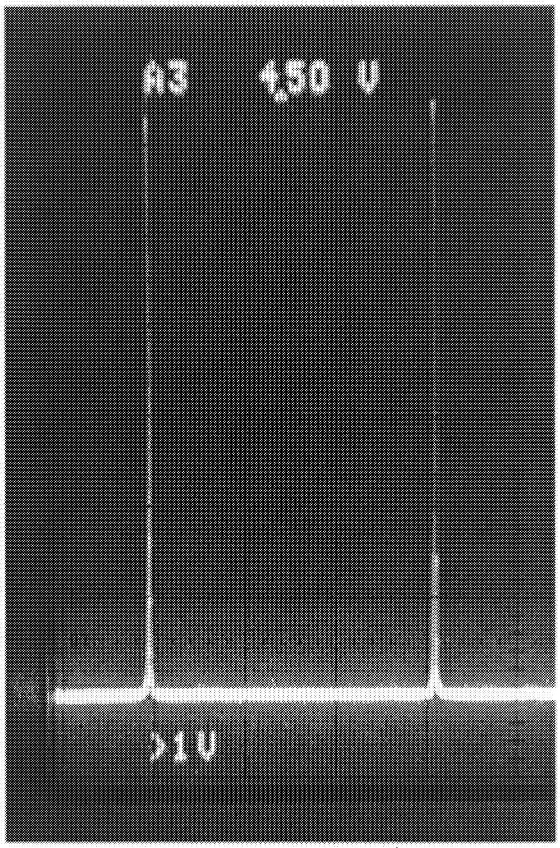

Fig. 4. Transmission spectrum of the doubler cavity.

The dependences of second harmonic power on input radiation power in the cases when BIBO and LBO crystals were used are given in Fig. 5. Peak conversion efficiency with the BIBO crystal was 36% (output radiation power at 425 nm was 270 mW), whereas with LBO crystal in the same resonator it was only 27% (200 mW).

Conversion coefficients γ obtained as a result of this work amount to γ_{LBO}=3.5 x 10^{-5} W^{-1} for LBO crystal and γ_{BIBO}=3.2 x 10^{-5} W^{-1} for BIBO one. Despite higher efficiency of SHG of BIBO crystal, its conversion coefficient was found to be slightly less than that of LBO crystal due to higher power-enhancement factor of the external resonator with this crystal. However it is obvious that conversion coefficient γ for BIBO crystal would be higher in the doubler cavity optimized for it.

At the output power of the second-harmonic radiation exceeding 270 mW with the BIBO crystal, which corresponds to 300 mW of power within the doubler cavity, high-magnitude power fluctuations of the second-harmonic radiation set in similar to those observed in [6].

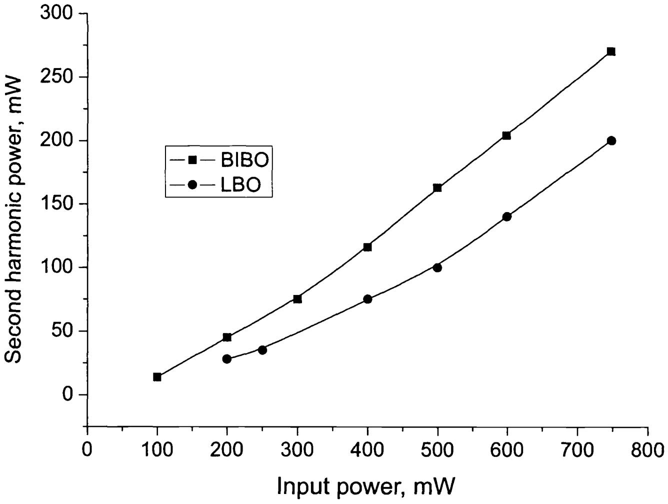

Fig. 5. SHG power as function of the input power

3. SUMMARY

Our experiments confirmed that the second harmonic generation in an external resonator with a BIBO crystal is more efficient than with LBO crystal for the radiation wavelength around 850 nm. For the first time stable second harmonic generation was achieved in an external resonator with BIBO crystal with intra-cavity power of 300 mW, which is more than double the previous best result in similar experimental conditions [6]. Increase in the maximum power of stable second harmonic generation with a BIBO crystal was achieved in the present work at the beam waist size, which was larger than the calculated value that corresponds to the maximum of the Boyd-Kleinman factor. The efficiency of the second harmonic generation with BIBO crystal reached 36% (output power at 425 nm was 270 mW), the efficiency of the second harmonic generation with LBO crystal in the same external resonator and at the same pump level (750 mW) amounted to only 27%.

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