Frequency conversion at 5.5 J, 10 Hz with an LBO Crystal in DiPOLE for greater than 4 hours operation

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Abstract

We report on type-1 phase matched frequency conversion in LBO (X-Y Plane), of 5.5 J, 10 Hz cryogenic gas cooled Yb:Yag laser operating at 1029.5 nm. LBO exhibited an efficiency of > 80% at a peak fundamental of 5.5 GW/cm^2 for 10 Hz operation at 10 ns. This was without any degradation or damage in the crystal.

1. Introduction

Ultra-high intensity laser-matter interaction applications, such as particle acceleration [1, 2], intense X-ray generation [3] and inertial confinement fusion [4] require lasers operating at multi-J to kJ energy levels. Proof-of-principle demonstrations have so far been carried out using laser facilities relying on flash-lamp pumped amplifier technology, which severely limits both the repetition rate and the efficiency of such systems [5]. However, in order to achieve practicable real-world applications of laser-matter interactions in industrial, medical and scientific fields, lasers reliably and efficiently delivering nanosecond pulses at multi-Hz repetition rates with a lifetime of several billion shots are required. Diode-Pumped Solid State Laser (DPSSL) technology represents a promising approach which is currently being extensively investigated. Yb^{3+}-doped Yttrium Aluminum Garnet (Yb:YAG) in ceramic form has been identified as one of the most promising active media for high energy, high repetition rate DPSSL systems [6]. However their lasing wavelengths near 1μm is not suitable for Ti:Sapphire or conventional OPCPA schemes (generating fs near 800 nm). This gap in wavelength is bridged by second harmonic generation (SHG) of 1 μm lasers using non-linear crystals [7,8], however, few SHG experiments with high energy 1 μm lasers at high repetition rates have been reported in the literature.

In a previous annual report we have done experiments on three different crystals and in this report we focus on the long term stability LBO crystal [9].

2. Experimental Setup

The fundamental beam was reduced in size from 18 mm to 10 mm square using a beam reducing relay-imaging telescope incorporating a vacuum spatial filter (VSF). This is shown in Figure 1. The VSF included a 3 mm diameter pinhole that acted as a baffle to prevent reflections being fed back into the laser chain. The output beam from DiPOLE was directed towards the telescope using a pair of mirrors M1 and M2 (HR @ 1030 nm). Mirrors P-M1 and P-M2 formed a periscope to raise the beam to the correct height ready to pass through the telescope. The beam reducing telescope was formed by a pair of plano-convex lenses L1 (f = 500 mm) and L2 (f = 350 mm) on either side of VSF. Mirror M4 then directed the de-magnified fundamental beam onto the frequency conversion crystal. The telescope was arranged such that the crystal was positioned at a relay-image plane of the main DiPOLE amplifier to obtain the best possible near-field uniformity. A HWP and QWP were placed at the output of the laser and adjusted with the help of a polariser. After correction, 98% of the fundamental energy was contained in the vertical polarization state. Leakage through the second mirror M2 was used for fundamental diagnostics, where lens L3 (with a focal length of 750 mm), and L4 (f = 75 mm), de-magnified the beam by a factor of 10 to provide a near-field image on Cam1, and a third lens L5 created a focus to record the far-field on Cam 2. The fundamental beam transmitted through M5 (Dichroic Mirror) was directed into a water-filled beam dump (BD1) and the second harmonic beam reflected from M5 was directed into a second beam dump (BD2). Reflection from an uncoated wedge (W1) positioned in front of BD1 was used to monitor the unconverted fundamental signal on a calibrated energy meter EM1 (QE50LP-S-MB). The second beam dump contained a solution of Azorubin Pure ($C_{20}H_{12}N_2O_7S_2Na_2$) dye in water for adequate absorption at 515 nm. A second uncoated wedge (W2) was positioned in front of BD2 to measure the second harmonic energy. The second harmonic energy was measured by using a calibrated energy meter EM2 (QE50LP-S-MB).

The crystal was held in place by a 50 mm mirror holder and had attached electronic actuators for remotely changing the angle of the crystal. This is shown in Figure 2.

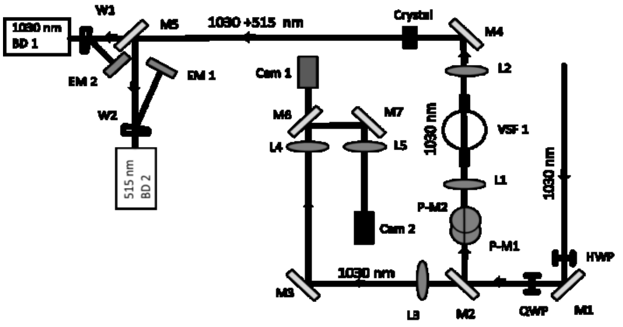


Figure 1: Schematic of the experimental setup to increase the fluence on LBO crystal. M1-M7: Mirrors; L1-L5: Lenses; HWP: Half-wave Plate; QWP: Quarter-wave plate; VSF1: Vacuum spatial filter; W1, W2: Wedges; Cam 1, Cam 2: Cameras, EM1, EM2: Energy meters; BD1, BD2: Beam dumps.

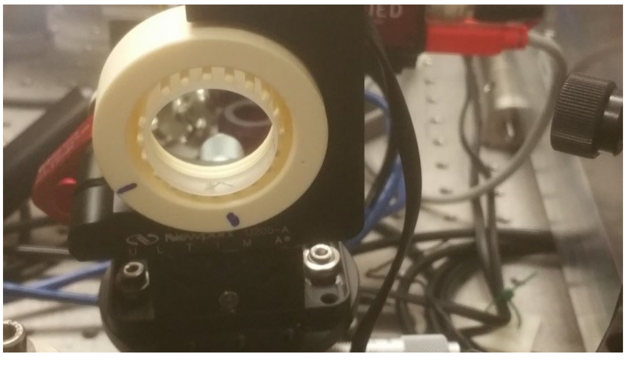


Figure 2: LBO crystal held in place by a laser printed holder which is fixed in a 50 mm mirror holder with electronic actuators for changing the angle of the crystal remotely.

3. Experimental results and discussion

As describe in an earlier annual report [9] a conversion efficiency of 82% at a fundamental peak intensity of 0.7 GW/cm^2. In this article we focus on the long term stability of the efficiency.

The output energy was monitored for more than 4 hours of operation at 10 Hz, at a fundamental energy of 5.5 J (Fluence = 5.5 GW/cm^2) as shown in Figure 3. The measured energy sees a reduction in the efficiency at 0.8 hours from 77% to 55% as shown in Figure 4. The return to the starting efficiency is achieved by adjusting the angle of the crystal. The time during the run at which the angle of the crystal was corrected is indicated by an arrow in Figure 4*Figure 4* .This is due to the increase in temperature of the crystal affecting the refractive index and therefore changing the angle at which the crystal is efficient. This could be a solution in which the efficiency is monitored and a feedback circuit is employed to change the angle of the crystal to bring the efficiency back to starting value. Another approach would be to have a thermal management system for the crystal.

A measurement of the temporal pulse of both the fundmental and the freaquency generated signal. This is shown in Figure 5 and they are similar in shape from the fundmental to the second harmonic.

During the 4 hour run there was no damage to the crystal and no visible damage to the crystal after the experiment. Therefore this means that the crystal and coatings can withstand 5.5 GW/cm^2.

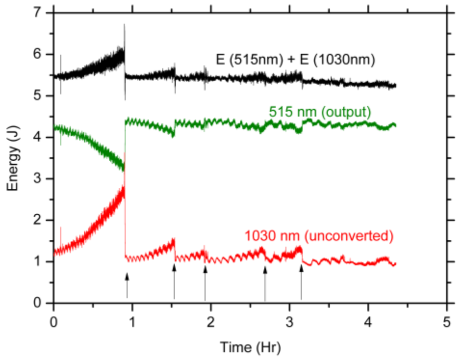


Figure 3: Long term energy stability for LBO crystal. The arrows indicate the time when the angle of the crystal is changed to recover the frequency conversion to the level at the start. The black line is the total energy, green line is the converted 515 nm and the red line is the unconverted 1030 nm.

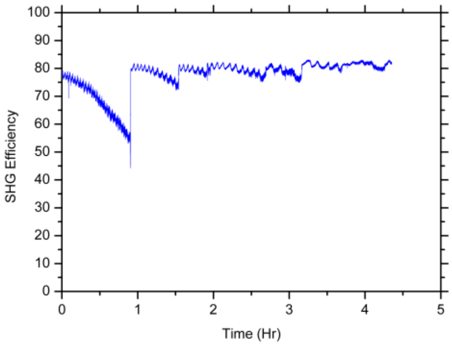
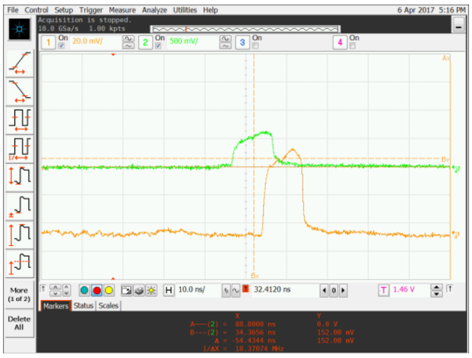


Figure 4: Long term efficiency for LBO crystal, over the four hours.



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Acquisition is stopped.
10.0 GSa/s  1.00 kpts
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                 X                   Y
A——(2) =  88.8000 ns          0.0 V
B---(2) =  34.3656 ns         152.00 mV
     Δ = -54.4344 ns          152.00 mV
  1/ΔX =  18.37074 MHz
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Figure 5: Temporal profiles of the fundamental (Yellow) and the frequency generated signal (Green).

4. Conclusion

Frequency conversion show that LBO (XY) type 1 is a very efficient method to create SHG with a high energy, high repetition rate (10 Hz) laser operating at a wavelength of 1 µm. There is however a thermal management issue with regards to long term stability. This can be managed in two ways. Either by a feedback mechanism to change the angle of the crystal or a temperature controlled environment. We are currently looking into these two approaches.

Acknowledgements

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