High power single frequency 780nm laser source generated from frequency doubling of a seeded fiber amplifier in a cascade of PPLN crystals

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Abstract: We report on the generation of over 900 mW of tunable cw light at 780 nm by single pass frequency doubling of a high power fiber amplifier in a cascade of two periodically poled Lithium Niobate (PPLN) crystals. Over 500 mW is generated in the first crystal. In the limit of low pump power, we observe an efficiency of 4.6 mW/W^2-cm for a single crystal, and 5.6 mW/W^2-cm for a combination of two crystals, with an enhancement of the doubling efficiency observed with two crystals due to the presence of second harmonic light from the first crystal acting as a seed for the second. We have frequency locked this laser source relative to a rubidium D2 hyperfine line and demonstrated its utility in a sophisticated laser cooling apparatus.

OCIS codes: (190.2620) Frequency conversion; (140.3510) Lasers, fiber; 020.7010 Trapping

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1. Introduction

Rubidium has rapidly become the workhorse of atomic vapor based instruments used for sensing and metrology. The unique properties of this atom at cold temperatures also make it a favorite species for laser cooling, and in particular for Bose-Einstein condensation experiments. Most of these applications, nevertheless, require as much as a Watt of laser power at 780 nm (the resonance frequency of the D2 line of rubidium) for cooling and internal state preparation. In particular, NASA is interested in performing a series of laser cooling experiments on the International Space Station over the coming decade which will involve rubidium atoms. A significant technical challenge for such missions is developing a robust, efficient, high power laser system. There have, however, been no convenient means for generating this much power with a single source, with the required narrow linewidths. The recent commercial availability of very high power (over 10 watt) fiber amplifiers at a wide

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variety of wavelengths in the near infrared, coupled with highly efficient frequency doubling using periodically poled nonlinear crystals [1,2], has the potential of dramatically altering the landscape of laser sources for atomic physics.

In this letter, we report on a 780 nm source suitable for atomic physics experiments involving rubidium employing an Er doped fiber amplifier (EDFA), which is confocally focused into a succession of two periodically poled Lithium Niobate (PPLN) crystals. This configuration acts as a “lens waveguide”, and for ideal focusing, no insertion loss, and no saturation, increases the SHG output of two crystals by a factor of four relative to that of one crystal [3]. We have characterized the performance of this laser system and demonstrated its utility in a laser cooling apparatus consisting of a 2-D magneto-optical trap (MOT) [4] loading a downstream ultra high vacuum MOT.

2. Experimental methods

A schematic of the apparatus is shown in Fig. 1. A commercial Yb/Er doped fiber amplifier (IPG Photonics model EAD-5-C-LP-JL) is seeded by a external cavity diode laser (New Focus Vortex model 6029), producing up to 5 W of cw power at 1560 nm. We have also used a distributed feedback (DFB) laser as a seed laser, and obtained similar results. Output from the fiber amplifier is collimated, and confocally focused into the first PPLN crystal (crystal-1), recollimated, and then again confocally focused into the second crystal (crystal-2). Each of the PPLN crystals (manufactured by Deltronics, Inc.) are 50 mm long, 0.5 mm thick, with a 19 μm domain period chosen for quasi-phase matching at 100° C. They are anti-reflection coated at both 1560 nm and 780 nm. The two mirrors after the first crystal are mounted on a rail, allowing the relative phase between the fundamental and the second harmonic to be varied by adjusting the path length between the two crystals. The difference of the index of refraction of air between the fundamental and the SH is about 1.6 ppm, so that a path length difference of about 49 cm corresponds to a full wave retardation of the 780 nm light with respect to the 1560 nm light.

A dichroic beam splitter (DBS) is used to separate the second harmonic (transmitted) from the fundamental (reflected). At low powers, each crystal had an insertion loss of approximately 4% for the fundamental. The SH power is measured on a NIST traceable photodiode (PD).

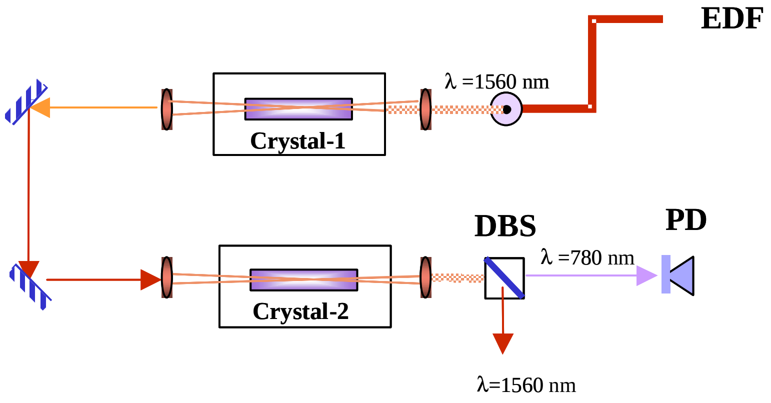

Fig. 1. Schematic diagram of experimental apparatus.

3. Results and discussion

A plot of second harmonic power versus fundamental power is shown in Fig. 2. Here we show the SHG power from the cascade of two crystals, along with the power from each of the crystals individually. The latter plots are obtained by replacing the second mirror in the set-up

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shown in Fig. 1 with a dichroic beamsplitter, so that we may monitor the SH power after the first crystal and direct only the fundamental to the second crystal. The power incident on the second crystal is of course reduced relative to that incident on the first, due to the insertion loss of the first crystal and the intervening optics, and, at higher powers, due to pump depletion. At low powers we achieve efficiencies of 4.6 mW/W^2-cm for crystal one and two separately, and 5.6 mW/W^2-cm for the two crystal cascade. The larger value for the cascade than for the single crystal results is a clear indication that the SH light from the first crystal is acting as a seed for the second. Insertion losses of the crystals and intervening optics, along with a non-ideal overlap of the fundamental and SH in the second crystal (simple plano-convex lenses are used to collimate the light from the first crystal and focus it into the second) prevent us from observing the doubling of the normalized efficiency that we would expect ideally. No evidence of photo-refractive damage is observed after many hours of operation at the highest pump powers.

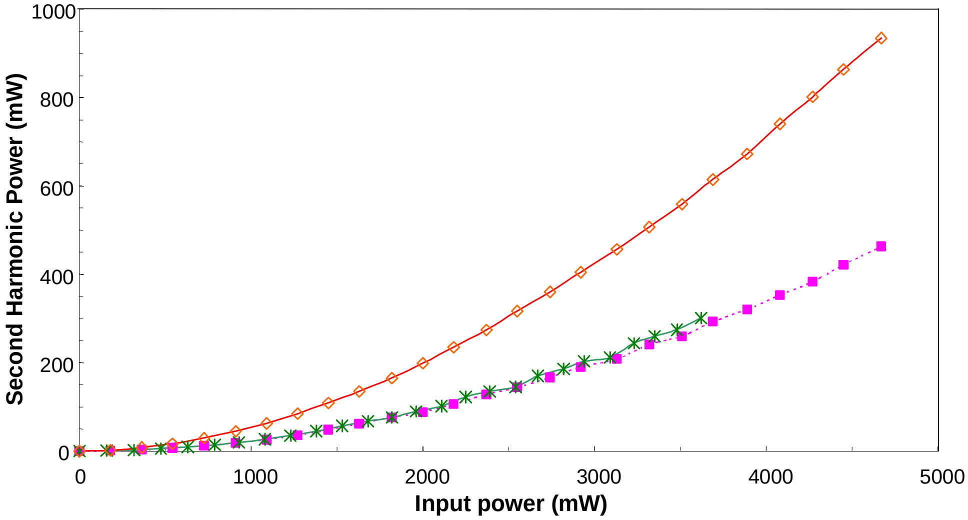

Fig. 2. Measured second harmonic power versus fundamental power after: a cascade of two crystals (diamonds), crystal-1 alone (squares), and after crystal-2, with the SH from crystal-1 removed by replacing the second of the two mirrors in Fig. 1 with a dichroic beamsplitter. For the first two cases the input power is measured at the entrance of crystal-1, for the third case it is measured at the entrance to crystal-2.

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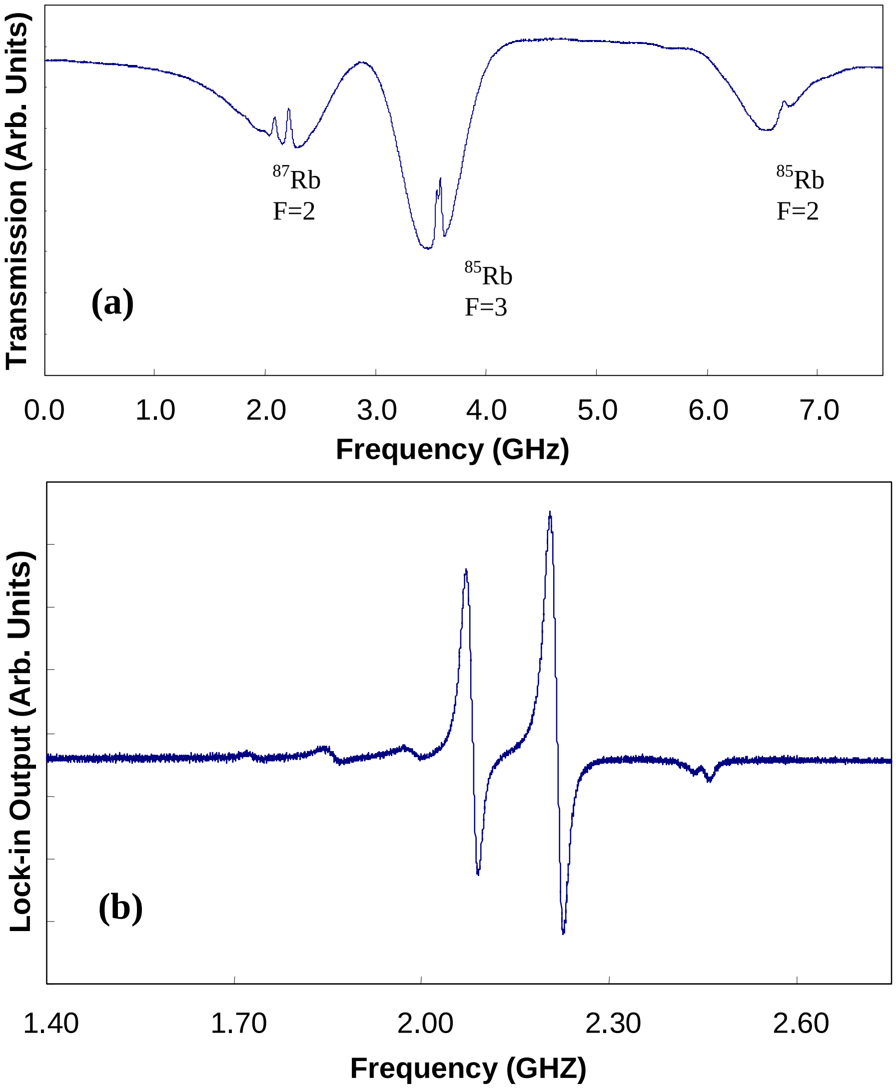

Fig. 3. (a) Saturated absorption spectrum of three of the rubidium D2 lines; (b) error signal derived from the ^{87}Rb F=2 spectrum by lock-in detection of the frequency modulated laser.

The laser system is readily tunable by adjusting the piezo voltage input of the seed laser. We can scan 50 GHz without adjusting the temperatures of the crystal ovens, and observe a 50% loss of power over that range (with a single crystal, we were able to scan 80 GHz before observing a comparable loss of power). We have servo-locked the seed laser frequency relative to the rubidium D2 hyperfine line using a standard atomic saturated absorption setup [5]. Figure 3(a) shows a saturated absorption spectrum of three of the rubidium D2 lines, while Fig. 3(b) shows an error signal generated by frequency modulating the laser output (using an acousto-optic modulator), and employing lock-in detection.

4. Conclusion

In conclusion, we have demonstrated the generation of over 900 mW of tunable cw light at 780 nm, by single pass frequency doubling in a cascade of two PPLN crystals. Over 500 mW is generated in a single crystal, corresponding to an absolute SHG efficiency of 10%. We believe this to be the highest cw SHG efficiency reported for bulk PPLN crystals in the ~1.5 μm wavelength range [6], and is comparable to the best cw results reported at any wavelength [1], with appropriate wavelength scaling.

The laser system we have described is remarkably easy to align and operate. To demonstrate its utility for atomic physics experiments, we have employed the laser system in a sophisticated laser cooling experiment in which a 2-D magneto-optical trap (MOT) [4] is used to load an ultra-high vacuum MOT. In terms of loading rates, the performance is comparable to a Ti:Sapphire based system.

We note that this system allows us to take advantage of the many sophisticated opto-electronic and micro-electro-mechanical devices that have been developed for the telecommunications industry and are designed to operate near 1560 nm. Finally, we also note that high power fiber lasers are available at a wide range of wavelengths, so that the techniques discussed in this letter may be applicable for other atomic wavelengths. In particular, high power Raman fiber lasers are available at 1178 nm, and could be doubled to produce the 589 nm sodium D2 line. This wavelength is of considerable interest for high power laser guide star applications, as well as for atomic physics experiments.

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