A High-Power 556nm Source for Laser Cooling of Ytterbium Atoms

Jiawen Pi, Vladyslav Ivanov, Subhadeep Gupta
Department of Physics, University of Washington

Background

The fine structure constant (α) is a fundamental scientific quantity because it characterizes the strength of the fundamental interaction between light and matter. Cold ytterbium (Yb) atoms are promising candidates for accurate measurements of this constant using atom interferometry techniques. It is possible to cool Yb atoms to temperatures of few micro-Kelvin (one millionth of a degree above absolute zero) using coherent laser radiation. This is achieved by using laser cooling, where atomic motion is cooled by counter-propagating resonant laser light at 556nm (green), a wavelength not easily reachable by common laser sources. Therefore, this project is devoted to construction of such a laser source to perform laser cooling of Yb.

Objectives

- •Design and build a bowtie cavity
- •Design and build a crystal heating system
- •Test a single beam path to test the performance of the crystal with the heating system.
- •Use a lock box to stabilize the cavity length
- •Install the LBO crystal inside the bowtie cavity

Method

•Light at 556nm can be produced by second harmonic generation (SHG) or "frequency doubling" of light at 1112nm (the fundamental).
•In SHG, a medium doubles the frequency of incident light through a non-linear process.
•We use a lithium triborate (LBO) crystal heated to 100 degree C to achieve the phase-matching for frequency doubling of an 1112nm fiber laser source.
• The efficiency of the non-linear process is strongly dependent on the intensity of the fundamental, we will increase the available 1112nm intensity using a resonant build-up cavity around the LBO crystal.

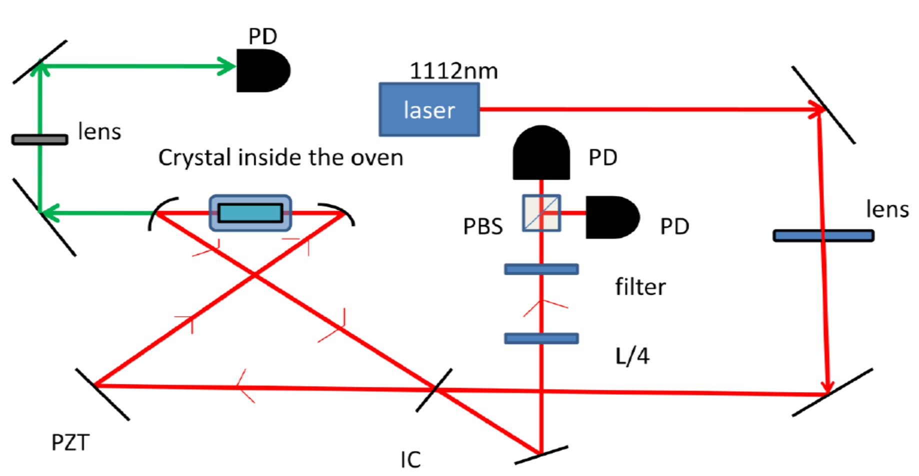
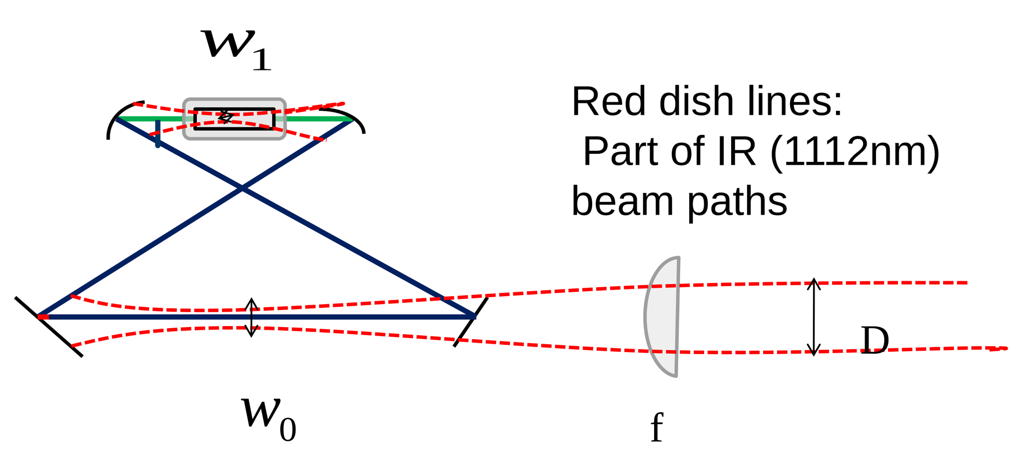


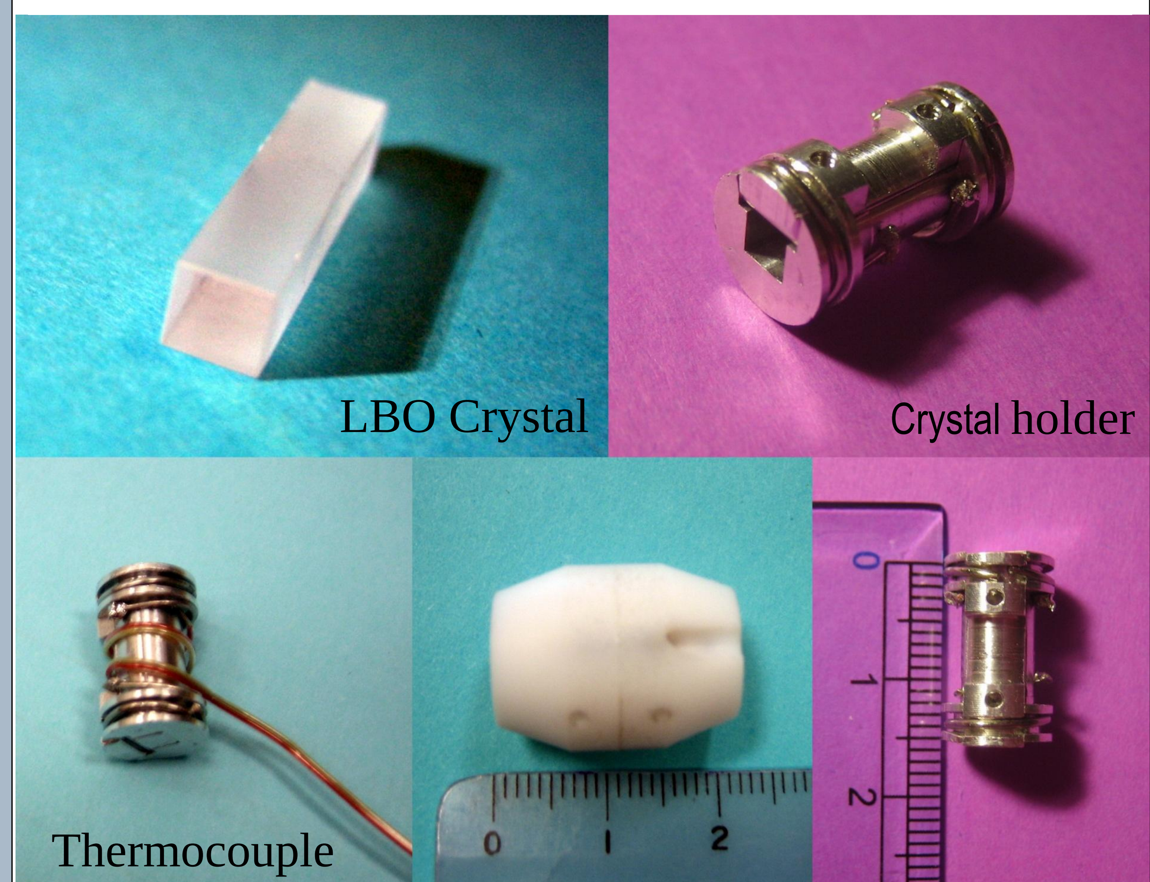
Figure 1: The bowtie cavity system. The slanted black lines are all mirrors. L/4 is a quarter waveplate. PBS is a polarized beam splitter. IC is the input coupler mirror to the cavity.

Heating Oven & Cavity Design

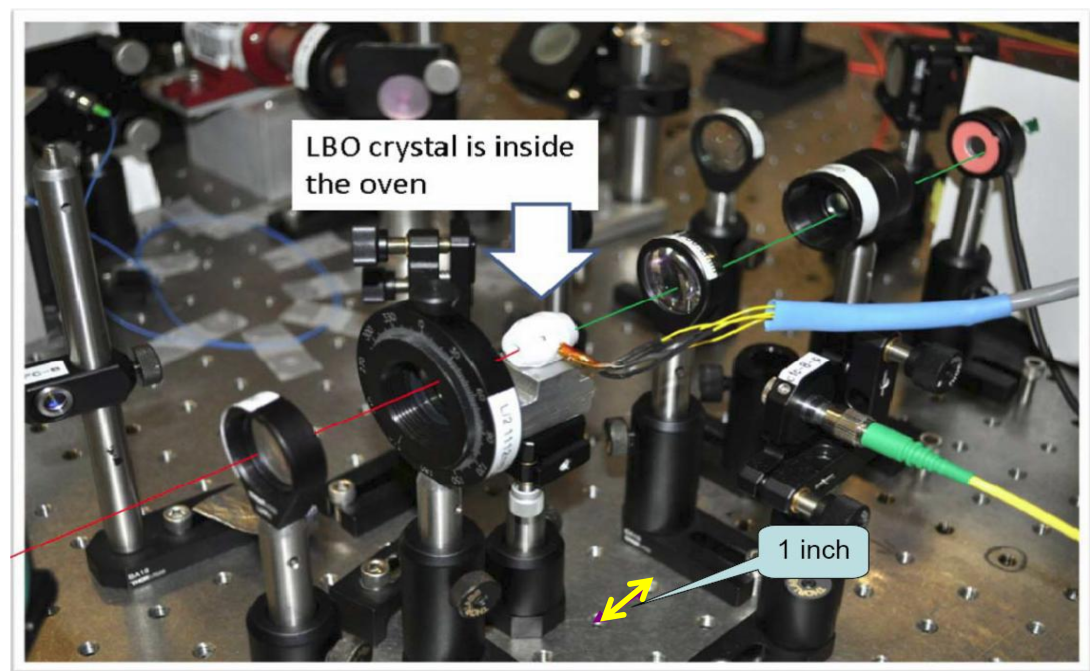
• Design the sizes of the bowtie cavity and an crystal heating system



- Using SNLO to get approximate lengths for a stable cavity
  - Length 1: 60mm
  - Length 2: 267mm
  - $w_1 = 36.25\mu m$
  - $w_0 = 261.98\mu m$
- Measure the waist of the beam is 0.6mm;
- f=400mm $f = \frac{w w_0 \pi}{\lambda}$
- The angle is 20 degree
- The enhancement: $A = \frac{1-R}{(1-\sqrt{RV})^2} \approx 47.9$



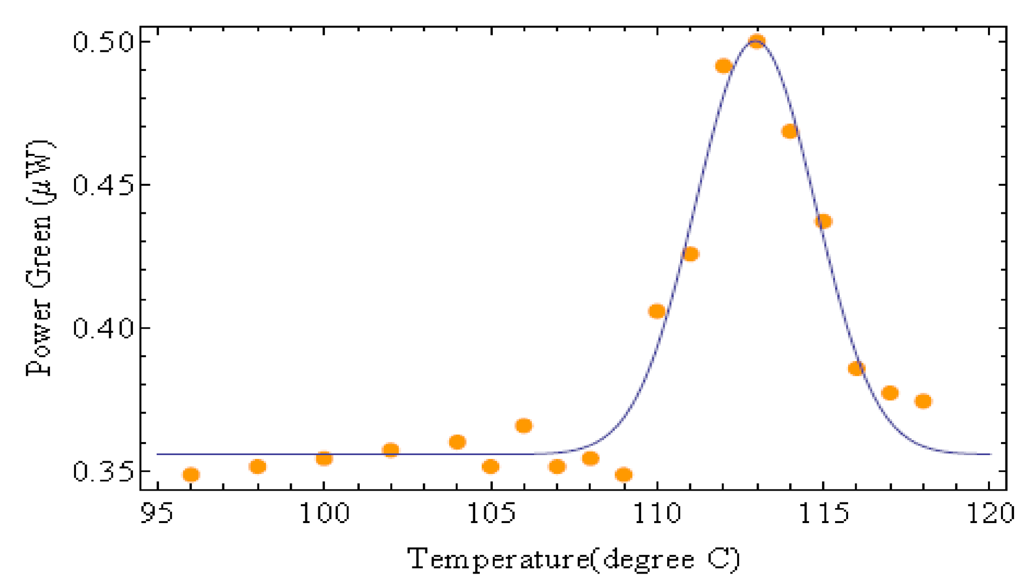
• Single beam path testing: measure how well the crystal performance, and how well the heating system works.



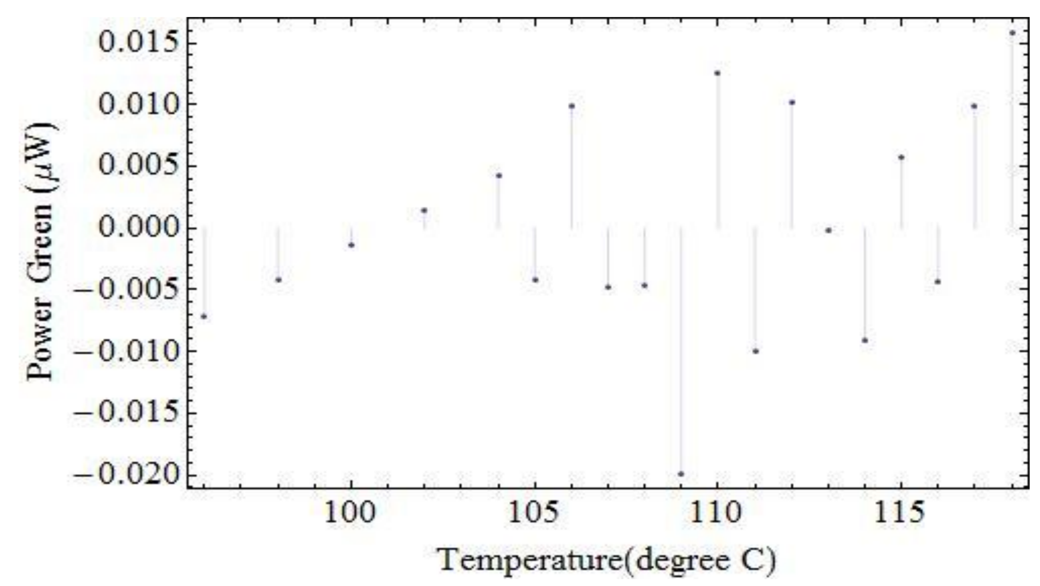
Testing Result

LBO crystal and heating system testing

• Temperature near the phase matching (laser Power at 1 watt)

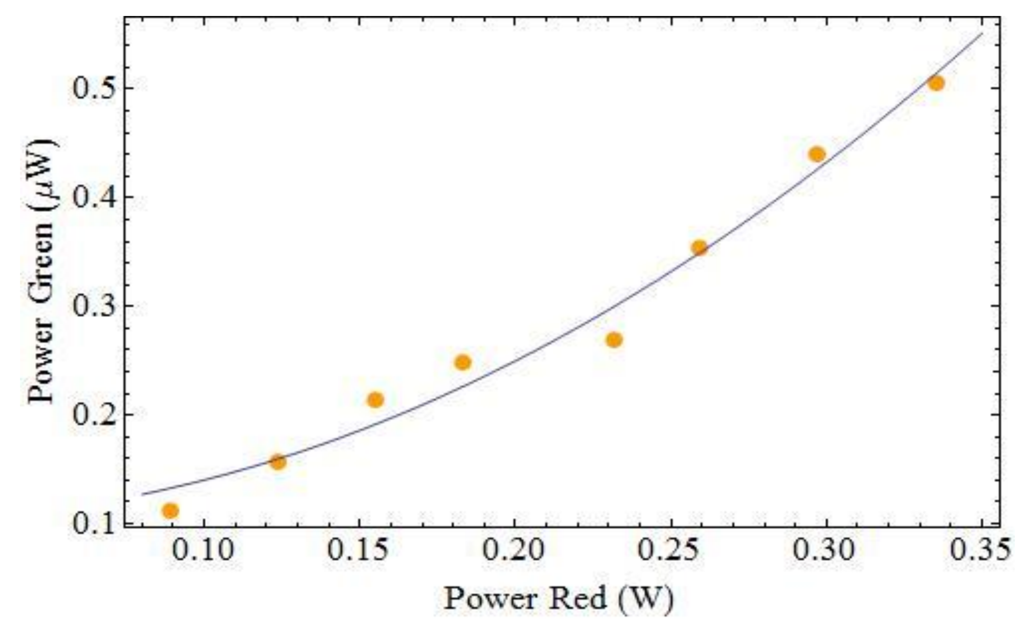


We can get the maximum green power at 113 degree C



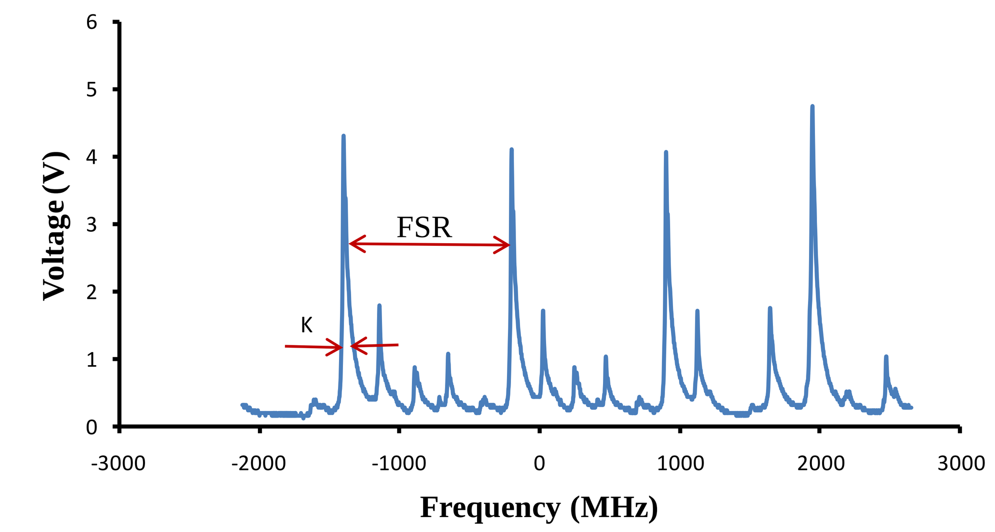
The heating system can perform better above 95 degree C

•Second Harmonic Generation Efficiency at 113 degree C



Theoretical value: PowerGreen $=2.57 \times 10^{-6}$ PowerRed^2
Fitting Function:
PowerGreen $=1.0382 \times 10^{-7} + 3.65521 \times 10^{-6}$ PowerRed^2

• Cavity without Crystal



➢Free spectral Range (FSR):

$$FSR = \frac{c}{L_1 + L_2} = 917MHz$$

➢ Full width at half Maximum(FWHM):

$$K = 119.4MHz$$

➢Calculate the performance of the cavity according

$$Finesse \approx \frac{FSR}{FWHM} = 10.25$$

Conclusion

After the single beam path testing, we find that crystal can produce the most green power around 113 degree C. It is higher than the expectation value 100 degree C, but it is still reasonable. At 113 degree, the produced green powers are agreeable with our expectation values, which means our crystal heating system working successfully. Moreover, from the error analysis, we find the heating system works better higher than 95 degree C. According to the Finesse, the cavity didn't perform well. I need to do more alignments of the cavity to get better results.

Future Work

We will install the crystal-oven assembly into the cavity shortly to test the performance of the complete SHG system for production of 556nm light. We expect to produce 2294 times more green power than the single path test at this wavelength for laser cooling of ytterbium. This system will form a part of the atom interferometry apparatus to measure the fine structure constant, of fundamental importance in condensed matter physics, atomic physics, and quantum-electrodynamics.

Acknowledgement

Special thanks to Ron Musgrave and Anders Hansen for giving me great advice on making the crystal heating system. This study would not have been possible without the support from the Ultracold Atoms and Molecules Research group.