Reducing UV Near-Field Beam Modulation on OMEGA EP by Angularly Detuning the Frequency Conversion Crystals

Kyra Horne
Fairport High School

LLE Advisor: Mark Guardalben

University of Rochester
Laboratory for Laser Energetics
Summer High School Research Program 2010

Abstract

The frequency-conversion crystals (FCC's) mounted in the OMEGA EP laser system are used to convert an infrared beam to a third-harmonic ultraviolet beam. Currently, the FCC's are angularly tuned to maximize the conversion efficiency. When operated in this manner, the laser damage thresholds of the current UV optics require that the IR laser intensity be maintained at a relatively low level (~1 GW/cm²). In this regime, small IR intensity variations produce large UV intensity variations, causing the UV beam to be highly modulated. We show, both in simulations and experimentally, that by angularly detuning the doubler crystal, the UV beam intensity modulation can be significantly reduced. Measurements on OMEGA EP show a reduction in peak UV fluence of 13% for the detuned FCC. Standard deviations of UV beam fluence distributions were 21% and 14.7% for the tuned and detuned cases, respectively, indicating a significantly smoother beam for the detuned FCC for the same UV energy. This should allow more energy to be delivered to a target while maintaining peak intensities below the damage threshold limit.

Introduction

Frequency-conversion crystals are used to decrease the wavelength (increase the frequency) of a beam. The frequency-conversion crystals in the OMEGA EP laser system convert an infrared beam to a third-harmonic ultraviolet beam in a two-step conversion process as shown in Fig. 1. The beam first passes through the doubler crystal and then through the tripler crystal.

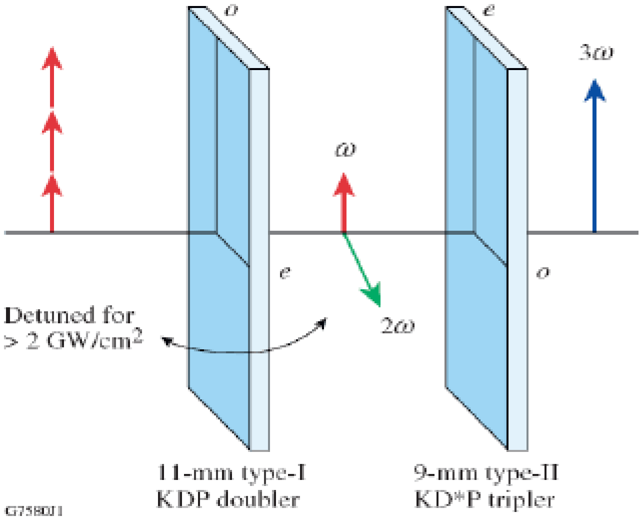

Figure 1: Schematic of the frequency conversion process using the doubler and tripler. Three infrared photons aligned with the o-axis pass through the doubler and two convert into a green light photon while the third remains infrared. The green and infrared photon then pass through the tripler and form an ultraviolet photon aligned with the e-axis.

The FCC's are angularly tuned to maximize conversion efficiency. However, they must currently be operated at a relatively low level of IR laser intensity, approximately 1 GW/cm^2, due to the low laser damage thresholds of the current UV optics. This results in a highly modulated UV beam. This large UV intensity variation lowers the laser energy because the peak intensities must be kept below the laser damage threshold (see Fig. 2).

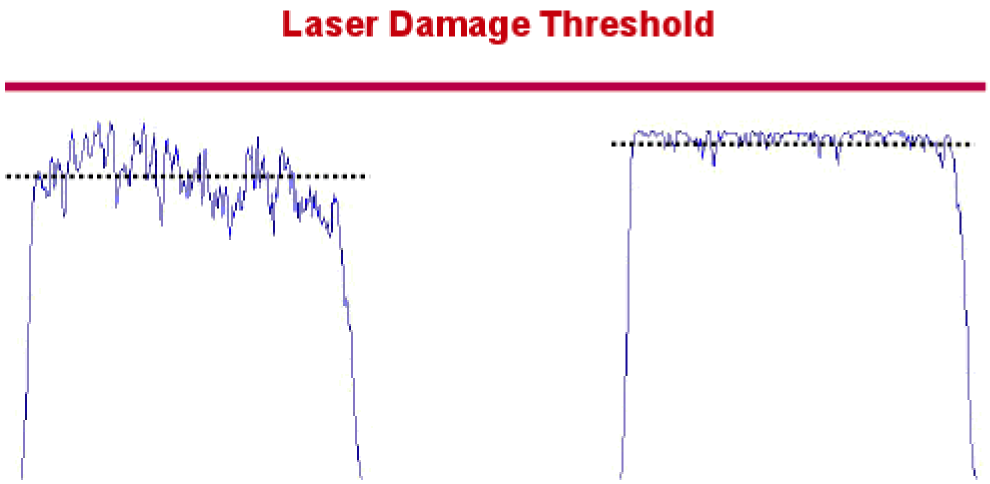

Figure 2. Beam intensity lineouts (left) with high modulation and (right) with reduced modulation. In both cases, the highest intensities must be beneath the laser damage threshold to avoid damage to the UV optics after the frequency conversion crystals. The beam with low modulation can be operated with a higher average energy.

In this work it is proposed that within the current operating regime of the OMEGA EP laser system, a detuned doubler can produce a smaller range of UV intensities than a tuned doubler. This follows the observation in Ref. 1 that intensity modulations can be reduced by detuning the tripler, albeit with some loss of conversion efficiency.

Simulation

Using predictions of the frequency conversion code *Mixette* (based on Ref. 1), graphs of UV output intensity versus IR input intensity were plotted at various combinations of doubler and tripler detuning. These plots were compared to determine the detuning angle that would produce the lowest UV beam modulation, while remaining within the OMEGA EP system's allowed IR input intensity level and beneath the UV laser damage threshold.

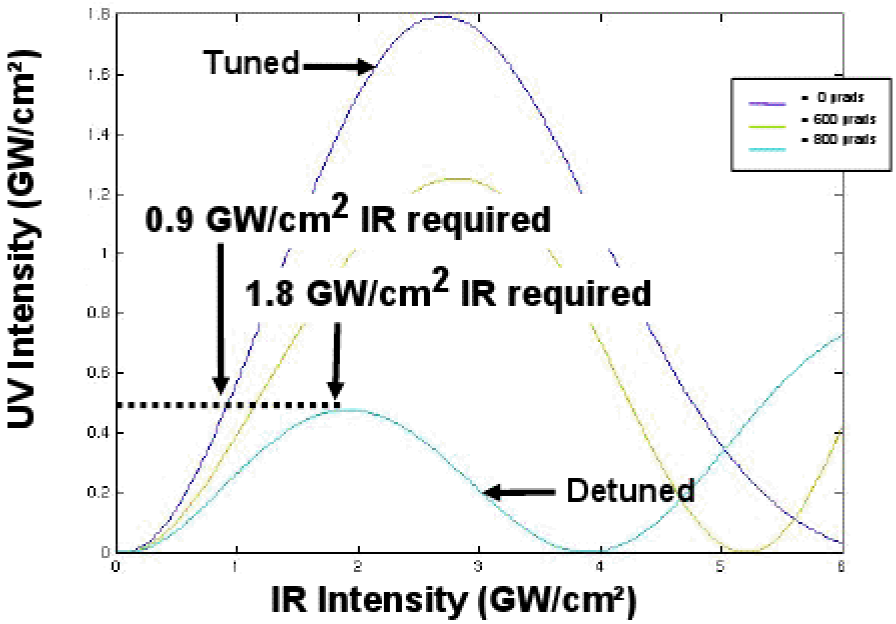

Figure 3: Graph of UV intensity vs. IR intensity. A tuned doubler requires less IR intensity input to achieve the same UV intensity as a detuned doubler.

Simulations (Fig. 3) confirm the proposal that a detuned doubler may produce less UV intensity variation. In Fig. 3, a UV intensity of 0.5 GW/cm^2 can be produced either using 0.9 GW/cm^2 of IR with a tuned doubler or 1.8 GW/cm^2 of IR with a doubler detuned by 800 µrad. In the first case IR intensity modulations produce large UV intensity modulations, while in the second case UV intensity modulations are minimized. It requires a greater amount of IR intensity input to achieve the lessened variation.

It was determined that the best system used a doubler detuned 800 µrad with a tuned tripler. This system also required a relatively low level of IR intensity to achieve significantly less UV beam modulation and had low angle sensitivity.

MATLAB simulations for the tuned and detuned cases were compared using the same measured IR beam and pulse shape and showed less modulation for the detuned case. In Fig. 4,

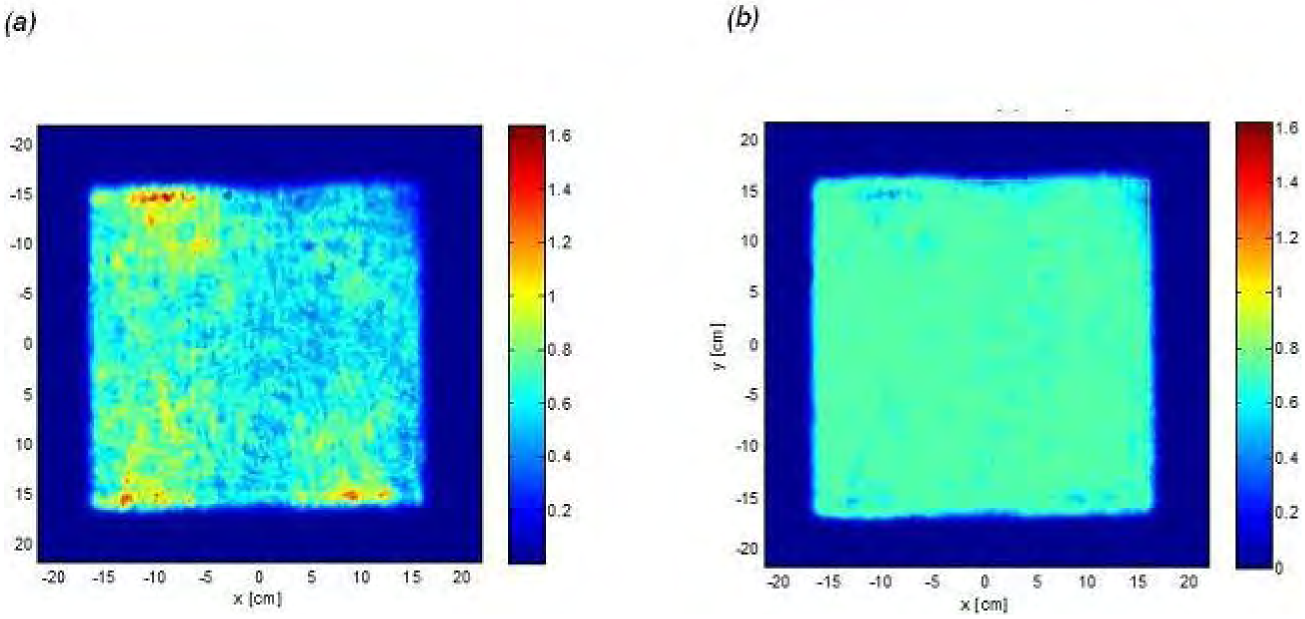

Figure 4: *Simulations of the UV output beam intensity (J/cm²) for (a) a tuned doubler and (b) a detuned doubler at 800 µrad. The tuned beam has higher modulation, a UV energy of 642 J, a contrast of 24.2%, and peak fluence of 1.62J/cm². The detuned beam has reduced modulation, a UV energy of 722 J, a contrast of 5.9%, and a peak fluence of 0.73J/cm².*

the UV beam fluence maps (J/cm²) simulated with MATLAB show an increase in UV energy from the tuned to detuned, 642 J to 722 J, respectively. The simulations also show a decrease in standard deviation in fluence (averaged over the beam) from 24.2% to 5.9% and in peak fluence (1.62 J/cm² to 0.73 J/cm²).

Experiment

The simulations were verified experimentally on OMEGA EP proving that detuning the crystals can produce a beam with reduced modulation. Shots were fired on the system and measurements were taken for the tuned and detuned-doubler cases (Figs. 5 and 6, respectively).

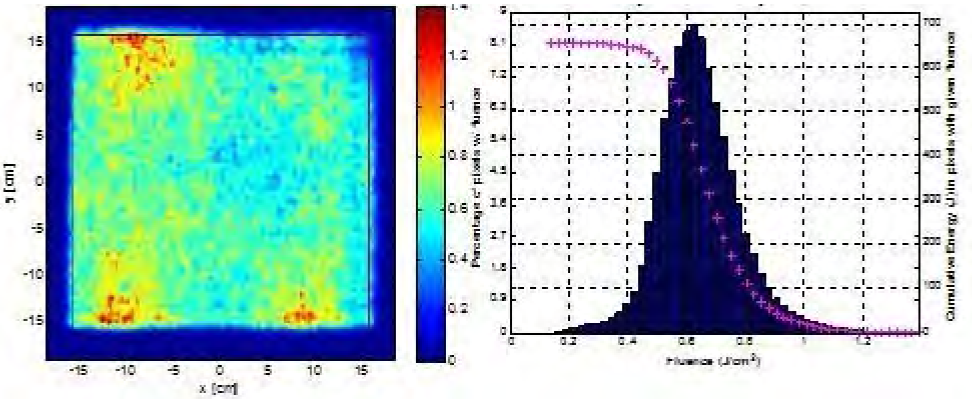

Figure 5: Experimental UV beam fluence map and histogram from a shot on OMEGA EP for a tuned doubler. The tuned beam has higher modulation, a UV energy of 683 J, a contrast of 21.2%, and a peak fluence of 1.39 J/cm².

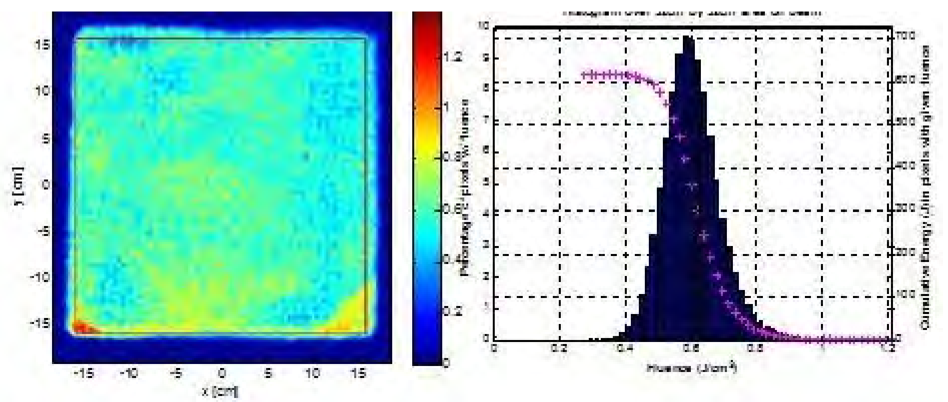

Figure 6: Experimental UV beam fluence map and histogram from a shot on OMEGA EP for a detuned doubler at 800 µrad. The detuned beam has reduced modulation, a UV energy of 694 J, a contrast of 14.7%, and a peak fluence of 1.21 J/cm².

The tuned doubler required 1680 J of IR input energy and produced a UV output energy of 683 J. The standard deviation was 21.2% and the peak fluence in the beam was 1.39 J/cm². The detuned doubler required 3939 J of IR input energy and produced a UV output energy of 694 J. The standard deviation was 14.7% and the peak fluence in the beam was 1.21 J/cm². The peak fluence was reduced by 13% and the standard deviation was reduced by nearly 7%. The reduction in peak fluence allows for a 13% increase in UV output energy for the beam.

Future Work

The experiment done on the OMEGA EP laser system served as a proof-of-concept experiment and was carried out at relatively low energies to ensure safety of the laser system. The next step is to increase the IR energy to show that more UV energy can be safely delivered to a target with a detuned FCC than a tuned FCC. This will require determining the proper amount of detuning for each pulse shape and input energy, and additional shots on OMEGA EP to confirm the simulations.

Acknowledgements

Thank you to Dr. R. Stephen Craxton for directing the LLE Summer Program and giving me the opportunity to do research at the LLE facility. I also thank my advisor Mark Guardalben for instructing and supervising me in this research.

References

[1] R.S. Craxton, IEEE J. Quant. Electronics, QE-17, No. 9, pp. 1771-1782, Sept. 1981