Simulations and experimental demonstration of energy clamping for harmonic generation at 1 GW/cm^2 for nanosecond pulses due to wavefront distortion/defocus in glass amplifier systems

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Introduction

There is growing interest in the development of optical parametric chirped pulse amplification (OPCPA) laser technologies for Multi-PW applications. These require the construction and development of suitable pump sources either based on Diode Pumped Solid State Lasers (DiPOLE[1] pump technology) or those that exist on large laser systems like Vulcan. We have previously described a temporally shaped 3 ns 30 J pump laser based on a combination of rod Nd:Glass amplifiers seeded by a CW pumped regenerative amplifier and a fiber seed source[2]. We model the frequency conversion of this at 3.1 J/cm^2 and 1 GW/cm^2 in 22 mm KDP, 64 mm DKDP and LBO for super Gaussian spatial profiles, and Gaussian (G) and super Gaussian (SG) temporal profiles, using SNLO[3]. As is common on glass-based laser systems, we observe far-field profiles which are distorted at the 30 J level: we incorporate this as wavefront curvature in our modelling. Because of walk-off between the fundamental and doubled light, this predicts a clamping effect dependent on crystal thickness. We complete this analysis on both KDP and DKDP of 22 mm and 64 mm thickness, respectively, the former crystal matching well experimental observed conversion efficiencies on our laser system. We anticipated and modelled enhanced conversion efficiency with the 64 mm fast growth DKDP, but observed severe clamping of the doubled energy. This study will be important for pump lasers, especially those systems being developed based on KDP and DKDP. As on DiPOLE[1], the preferred option appears to be ~15 mm thick LBO which has a greater (>3) non-linear coefficient and a smaller (<3) walk-off angle.

Optical Layout and Results

The 30J pump laser is shown in Figure 1. It consists of a series of Nd:Glass Rod phosphate amplifiers, beam expansion being carried in VSFs before finally being amplified at a diameter of 35 mm in a double pass 45 mm diameter amplifier. This laser system has been modelled in MIRÓ[4], which is able to predict the saturation effects in the final amplifier.

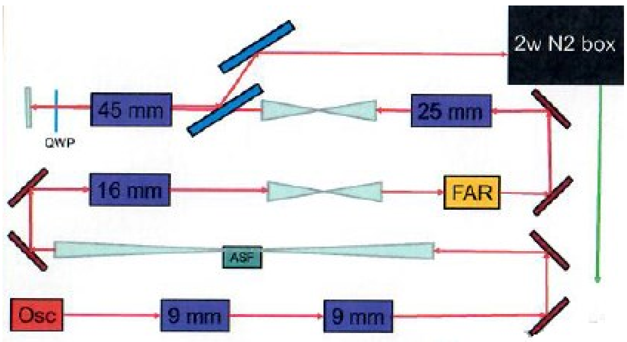


Figure 1 30J pump laser used for frequency doubling studies.

The Type 1 KDP and DKDP doubling crystals are housed in a nitrogen purged enclosure. Phase matching is achieved by mounting them on a computer controlled rotation stage. We monitor the far-field beam profile at the 45 mm diameter amplifier at low energy when the smaller rod amplifiers are operating, as well as at full energy with the larger amplifiers. The conversion efficiency for spatial super-Gaussian and temporal Gaussian and super-Gaussian beams from this laser system has been modelled in SNLO[3]. **Importantly**, this conversion efficiency is modelled and obtained at the ~57% level in thin crystals for flat wavefronts and wave-front curvatures changes which are similar to those observed in our far-field measurements where the beam can typically de-focus by more than seven times on full energy shots.

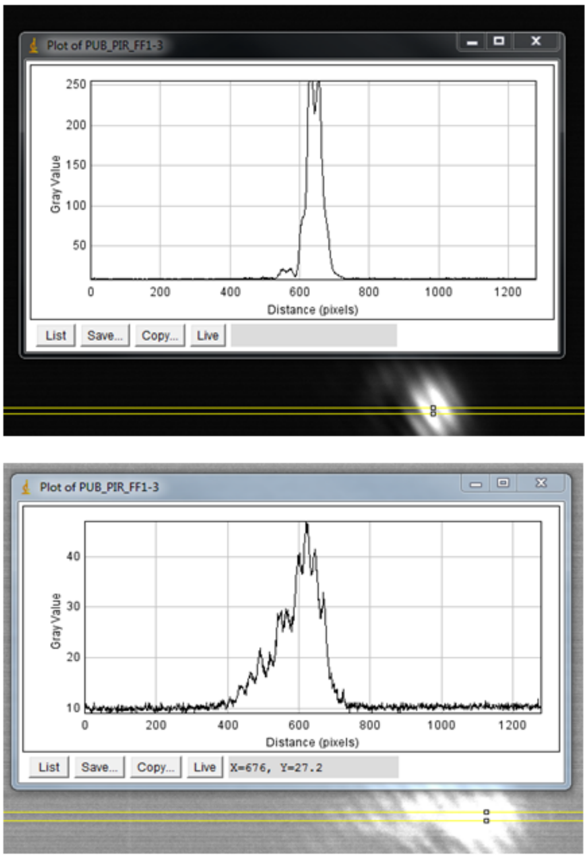


Figure 2 Far-field profiles on low energy and full energy shots

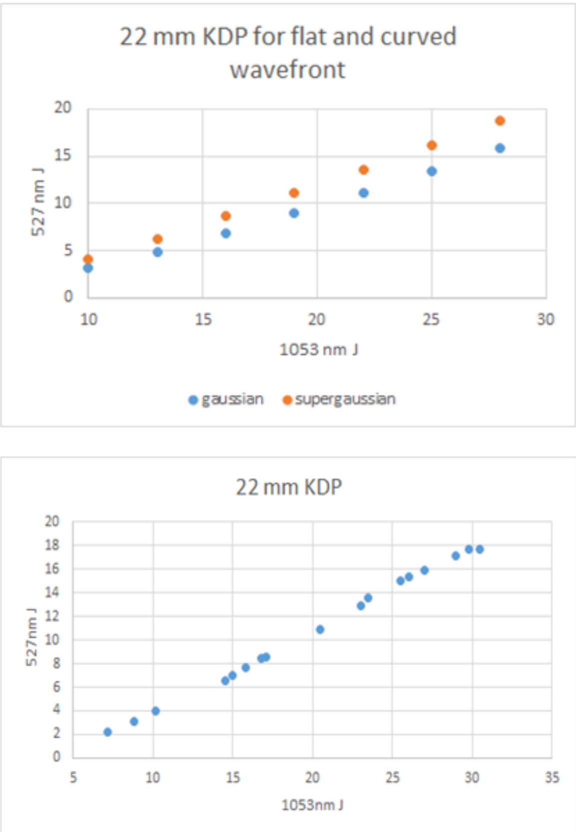


Figure 3: Computed and measured conversion efficiency for 22 mm KDP for 30 J 3 ns pulses at 3.1 J/cm^2

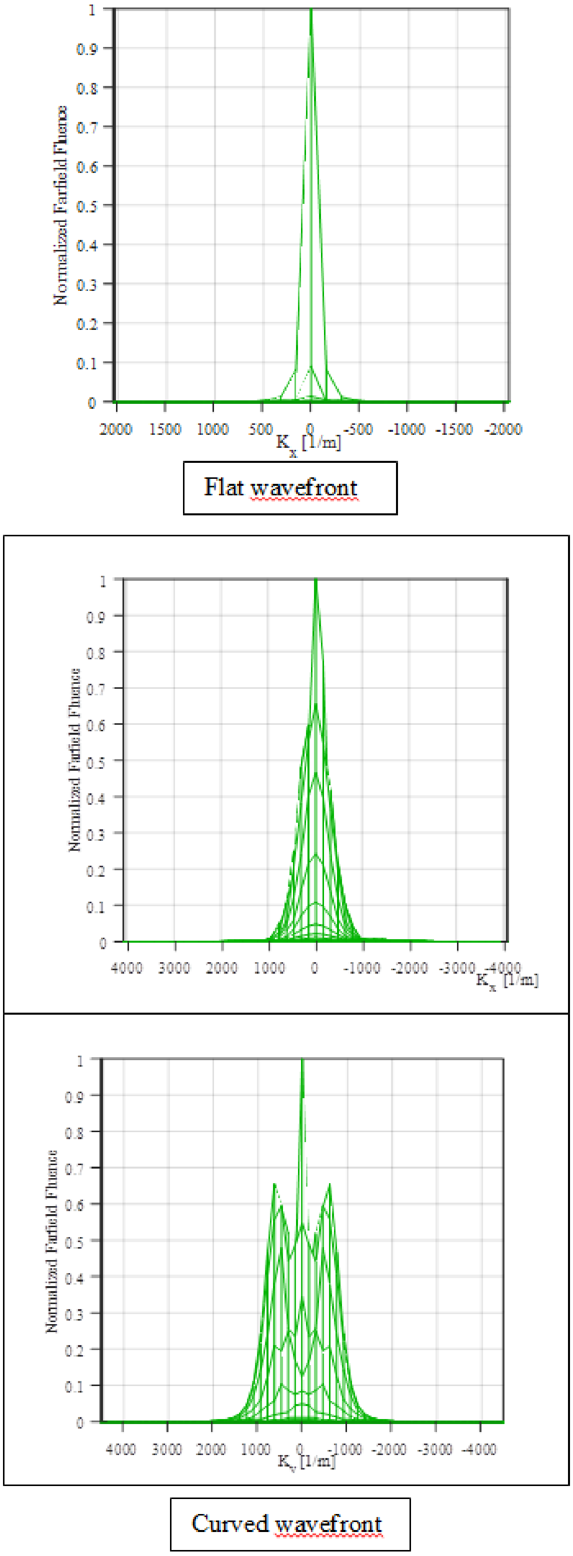
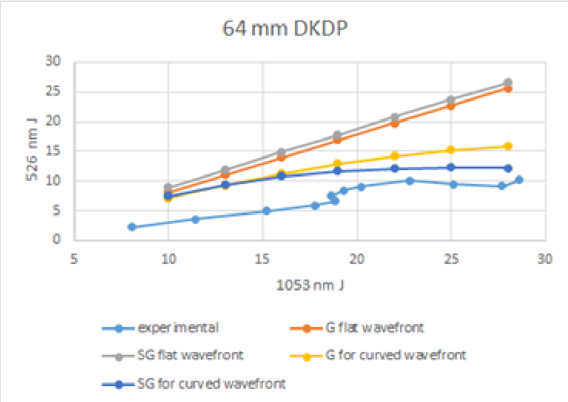


Figure 4: Corresponding far field beam profiles using SNLO after frequency doubling for flat and curved wavefronts (200m) in walkoff and non-walkoff planes

Our second crystal is a 64 mm thick DKDP – computed conversion efficiencies using SNLO are shown in Figure 5. Assuming a well collimated beam, the efficiency should approach 95% in these longer crystals. The graph shows efficiency at the correct phase matching angle, again for both temporal Gaussian and super-Gaussian beams. The experimental data and simulations demonstrate the clamping we observe. Other effects in longer crystals that may affect conversion efficiency could include fast and slow growth anomalies, optical axis change during growth and AR coatings – this may need further investigation.



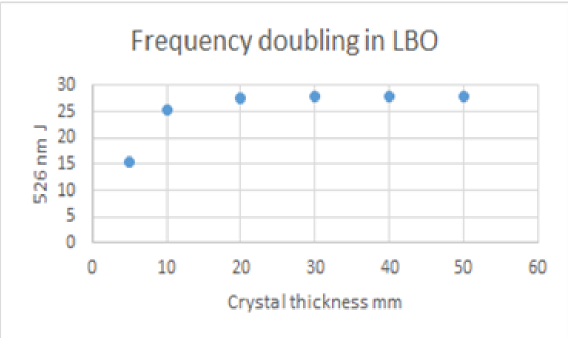


Figure 5: Experimental and simulated conversion efficiencies obtained in thick DKDP and LBO for 28J

Conclusions

The efficient frequency doubling of nanosecond 1053 nm sources will require further studies – for beams from glass amplifier systems which show wave-front distortion, this is likely to utilize ~15 mm LBO crystals and/or wave-front corrected laser and or adaptive optic systems as demonstrated on DiPOLE.

References

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