Cascaded Plasma Mirrors for Two-Color-Driven Harmonic Generation

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Abstract: We experimentally demonstrate enhanced third and fourth harmonic energy using a phase-controlled two-color beam in a multi-pass plasma mirror set-up. Maximum enhancement of 1.6× was measured for on-target intensity of $1 \times 10^{19} Wcm^{-2}$.

1. Introduction

High harmonic generation from plasma mirrors in the relativistic regime can produce high-efficiency low-order [1] and high-order harmonics [2, 3] of the fundamental light. In the relativistic regime, high-harmonic generation (HHG) from plasma mirrors is well described by the Coherent Synchrotron Emission (CSE) [4, 5] model. During each cycle of the pulse, electron bunches undergo synchrotron-like trajectories and emit intense bursts of radiation in the specular direction. The periodic emission of coherent, broad-bandwidth light manifests itself as harmonics of the incoming laser light. The efficiency of HHG is dependent on the dynamics of the electron bunches which in turn depends on the waveform of the incoming light. Two-color beams provide a method to control the waveform of the driving laser by changing the relative phase between the two colors. Previous simulation [6, 7] and experimental work have shown enhancement in the harmonic efficiency by using a two-color beam to drive a plasma mirror. In previous experimental work [8, 9] transmission optics (second harmonic generation crystals) have been used to synthesize a two-color beam, this is not ideal for high-power systems due to non-linear effects in transmission and the low damage threshold of such optics. In this work, an initial plasma mirror is used to generate a two-color beam (consisting of 800nm light and its second harmonic) this beam is then refocused onto a subsequent plasma mirror. We show spatial measurements of the generated third and fourth harmonic with both suppression and enhancement compared to a single-color driving laser depending on the relative phase between the two colors.

2. Experimental Set-up

The experiment was conducted using a 20TW Ti-Sapphire laser with 25fs pulses centered at 800nm, pulse energy can be varied from 10-400mJ. The experimental setup (Figure 1) consists of three plasma mirrors in succession, PM1 (not shown), PM2, and PM3. The first (PM1) is driven at sub-relativistic intensities and is used to improve the temporal contrast of the pulse, it has 80% reflectivity for the fundamental light and provides two orders of magnitude improvement in temporal contrast [10]. While PM2 and PM3 are driven at relativistic intensities. The second plasma mirror (PM2) is used to generate the two-color beam and has 50% reflectivity for the fundamental and 15% reflectivity for the second harmonic [10]. Harmonics above the second order are produced by PM2 but are dumped due to poor reflectivity of the steering optics for wavelengths below 400nm. The two-color beam then travels through a 100μm fused-silica wafer, the angle of the wafer is adjusted to change the relative phase between the two colors. The beam is then focused onto PM3, and the third and fourth harmonics generated from this plasma mirror are captured by CCDs and used to study the effect of the two-color beam on the generated harmonics.

3. Results

In Figure 2 we compare the energy of the reflected third and fourth harmonic from PM3 for a two-color and one-color beam as a function of pulse energy before compression. A one-color beam was produced by using a dielectric mirror before PM3 which does not reflect light at 400nm. Changing the pulse energy changed the intensity on-target which increased the percentage of second harmonic (1-10%) in the two-color beam from PM2. With no wafer in place, we saw suppression of the third and fourth harmonic from the two-color beam compared to the one-color beam. With the wafer in place at an angle of 25°(orange circles) we saw an enhancement in the harmonics produced by the two-color beam. A maximum energy enhancement of 1.6 was seen at 500mJ which

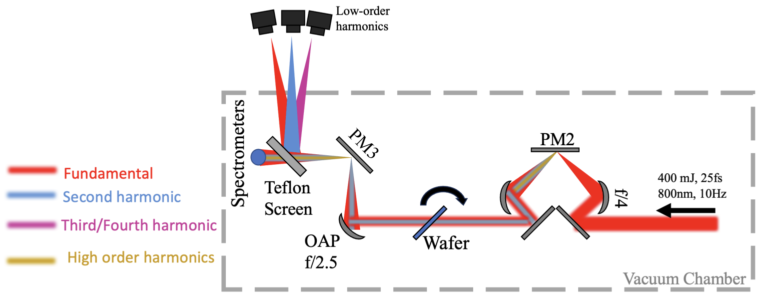

Fig. 1. Experimental set-up showing the multi-pass plasma mirror configuration.

corresponds to an on-target intensity of $1 \times 10^{19} W cm^{-2}$. It should be noted that the increase in enhancement as a function of pulse energy is both due to an increase in on-target intensity and an increase in the fraction of second harmonic present in the beam.

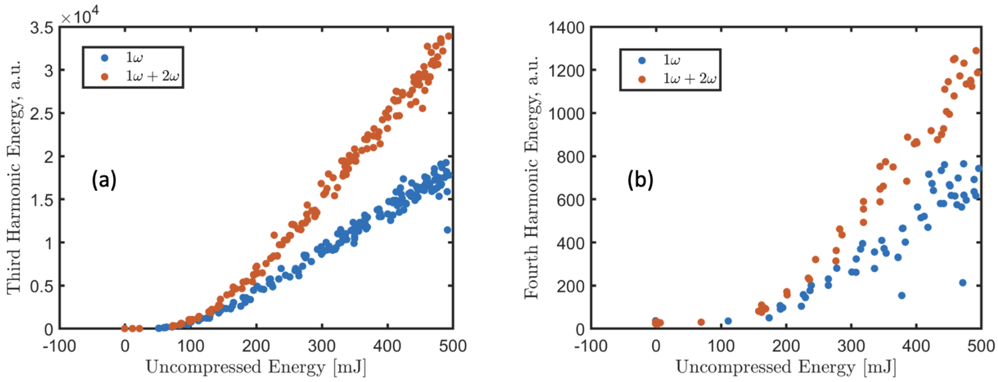

Fig. 2. Experimental measurements for the third (a) and fourth (b) harmonic energy as a function of the pulse energy before compression for a two-color and one-color driving beam with wafer angle at 25°.

4. Conclusion

We have demonstrated control over the two-color waveform incident on the plasma mirror using a wafer to change the relative phase between the two colors and shown an enhancement in third and fourth harmonic energy with a multi-pass plasma mirror set-up.

5. Acknowledgments

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