PRE-CHIRP CONTROL BROADBAND NON-COLLINEAR OPTICAL PARAMETRIC AMPLIFIER FOR THE FUTURE LASER WEAK-FIELD ACCLELERATOR

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Abstract

Ultra-short pulse has been proved to be a very useful tool for accelerating electron close to GeV now. But limited by gain narrowing effect, conventional CPA technology is quite hard to get less than 30fs at high energy level. Non-collinear optical parametric amplification (NOPA) looks more and more attractive for generating super-broad bandwidth pulse, which is possible to be compressed to ultra-short pulses. Previous NOPAs, pumped by 400nm pulses, were using BBO crystals to reach shorter signal pulse durations. But the associated spectral bandwidths are still strongly linked with higher order nonlinear effects, which make it quite difficult to get higher energy with short pulse duration. Here we proposed to use pre-chirped few nm bandwidths around 515nm pumped pulses to amplify ultra-short pulses centered 800nm. In our design, we have found a new geometry configuration which support that we have possibility to get amplification from 728nm to 900nm, which will support to less than 10fs by well re-compression. This design is well adapted for BBO crystals. But the idea could be used also for other crystals.

INTRODUCTION

Ultra-short pulse has been proved to be a very useful tool for accelerating electron close to GeV now [1]. Searching for the method to amplify around 10 femtosecond or even shorter than few-cycle optical pulse becomes a challenge [2]. Up to now, there are two ways based on the optical parametric amplification (OPA). One is traditional femtosecond OPA, amplifying the femtosecond pulse by femtosecond pump. Limited by the group velocity mismatch (GVM), which will cause the split between the pump and the signal, the pump intensity and the damage threshold of the nonlinear crystal, it is quite difficult to get the high output energy, normally at 10-100μJ levels [3,4]. Another solution is to use optical parametric chirped pulse amplification (OPCPA), amplifying the stretched chirp signal by high-energy Q-switched nanosecond pump [5,6]. But, the pump-to-signal conversion efficiency is quite poor in most such kinds of system [7,8]. Now, more and more people try to use picosecond pulse as the pump source to increase the pump intensity, which will increase the pump-to-signal conversion efficiency. Here, we proposed one compensation design by realizing instant perfect phase matching through pre-chirp control for broadband non-collinear optical parametric amplification, which is using few nm bandwidths around 515nm pumped pulse to amplified ultra-short pulse centered at 800nm. This design is well adapted for BBO crystal. But the idea could be used also for other crystals.

NONCOLLINEAR GEOMETRY

Pump Wavelength Selection

Based on the parametric bandwidth equation [9], we can get the relationship between the parametric bandwidth and the center wavelength of the pump in Figure 1 by fixing the wavelength of the signal at 800nm. Here, the nonlinear crystal, which we select, is fixed to BBO. It shows that when the central wavelength of the signal is 800nm, we can get nearly maximal parametric bandwidth while the central wavelength of the pump is around 515nm. Such kind of pump wavelength is exactly match with the second harmonic generation (SHG) of 1030nm, which can be produced from Yb:YAG or Yb:KGW.

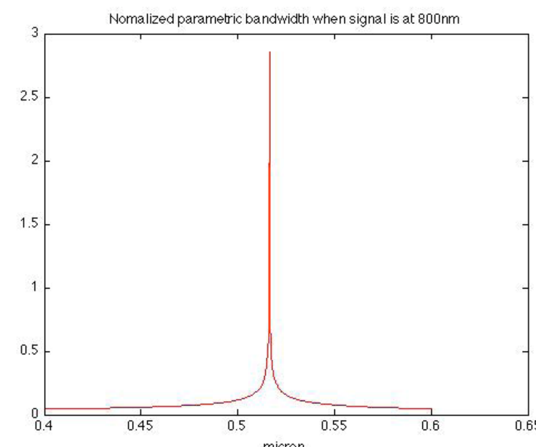

Figure 1: Maximum parametric bandwidth when signal wavelength is 800nm. X-axis is pump wavelength, Y-axis is normalized parametric bandwidth.

Magic Angle Configuration

After selecting the central pump wavelength at 515nm, we just change the signal as 725nm, 740nm, 750nm, 800nm and 900nm. We calculate the non-collinear angle α by changing the phase matching angle θ_{pm}, while we keep perfect phase matching ($\begin{matrix} \Delta k = k_p - k_s \cos\alpha - k_i \cos\beta \\ k_s \sin\alpha = k_i \sin\beta \end{matrix}$). The results show in Figure 2. It shows that if we take non-collinear angle as

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$\alpha = 2.54^\circ$, while the phase matching angle as $\theta_{pm} = 24.5^\circ$ (which we call "Magic Angle configuration), we can minimize the phase mismatch for the whole signal spectrum to get higher energy transfer efficiency.

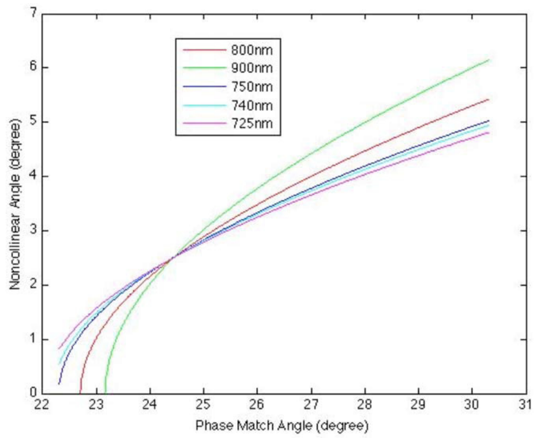

Figure 2: Phase matching angle vs. non-collinear angle when we use the pump wavelength as 515nm, but select different signal wavelength.

PRE-CHIRP CONTROL

Principle

In the case of linearly chirped pump and signal pulses, it is evident that there are many spectral components for which the phase matching condition is not perfectly satisfied. Such a partial phase matching decreases the energy transfer efficiency over the entire signal bandwidth. However, if we can adjust the relative temporal distributions of the pump and the signal to make sure that all the spectral components perfectly satisfy the phase matching condition, we could increases the energy transfer efficiency of the parametric process. At the same time, the gain bandwidth would match the parametric bandwidth. This is the main idea of the temporal synchronization by pre-chirp control in broadband non-collinear optical parametric amplifier.

Pump without Angular Dispersion

Based on the above non-collinear geometry, we analyse the temporal synchronization requirement of the spectral components for perfect phase matching. If the pump pulse has no angular dispersion, the analysis result shows that if we stretch the signal to be almost linearly chirped (by a grating stretcher or the prism pairs with Brewster angle cutting for example), we can then use a stretcher/Dazzler combination to generate the special chirp shape for the pump, as show in Figure 3. The graph should be simply interpreted as the relative chirp between pump and signal pulses since the corresponding spectral components will have to be synchronized to satisfy the phase matching. When all chirp requirement are satisfied, assuming 1.6nm bandwidth pump pulses (514.2nm-515.8nm), results in more than 170nm perfect phase match amplification bandwidth (728nm-900nm), which support less than 10fs.

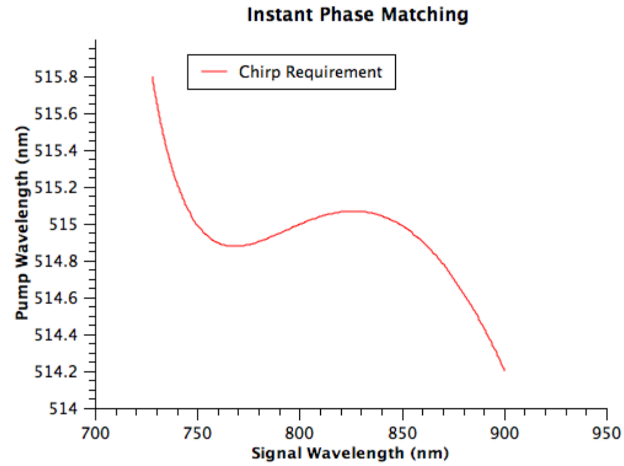

Figure 3: The relative chirp shape of signal vs. pump.

Pump with Angular Dispersion

If pump has angular dispersion, things will be changed. By using a prism coupled with a telescope consisting of two convex lenses as Figure 4 [10], we can also realize the broadband amplification for each spectrum components. While we keep the same non-collinear geometry as above, but put a small angular dispersion as $-0.1^\circ/1.6nm$, if we still try to keep amplifying almost linearly chirped signal, we have to match a totally different chirp shape for the pump. Especially when the crystal is put on the position just off the focus of the pump, the chirp requirement is shown as Figure 5. The left part looks as a hyperbolic function, while the right part is as a quadratic curve, which can be realized from the fiber laser source [11].

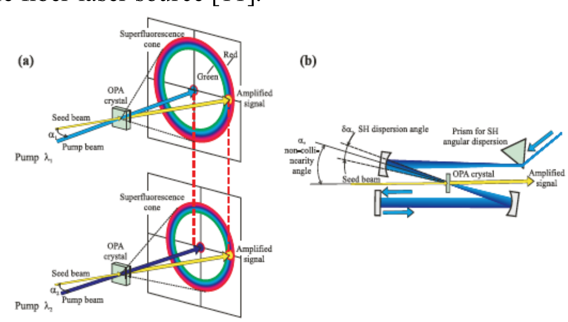

Figure 4: The pump tilt adjustment staff.

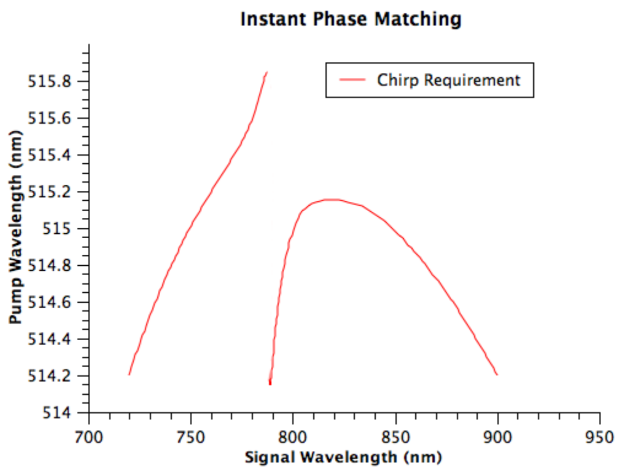

Figure 5: The relative chirp shape of signal vs. pump.

CONCLUSION

By using a stretcher/Dazzler combination, we could generate the special shape chirp pump pulse. Combined with an almost linearly chirped signal pulse generated by a grating stretcher or the prism pairs with Brewster angle cutting, all spectral components of the pump and the signal can satisfy the temporal synchronization to get broadband perfectly phase matched output for the case of pump without angular dispersion. For the case of signal with angular dispersion, just off the focus of the pump, the pump needs to have both a hyperbolic part and a quadratic part chirp. The gain bandwidth mainly depends on the bandwidth of the signal and the chirp shape of the pump and the signal. Such pre-chirp control can satisfy the temporal synchronization of the corresponding spectral components for perfect phase matching. This is the key factor to increase the energy transfer efficiency and to match the parametric bandwidth with the gain bandwidth. This new method is also suitable to any other non-collinear geometry.

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