PHOTOINJECTOR DRIVE LASER TEMPORAL SHAPING FOR SHANGHAI SOFT X-RAY FREE ELECTRON LASER*

Chunlei Li[1], Lie Feng[1], Xingtao Wang, Wenyan Zhang, Xiaolei Dai, Jinguo Wang, Haixiao Deng[1], Bo Liu[1†], Shanghai Advanced Research Institute, Chinese Academy of Science, Shanghai, China
[1]also at Shanghai Institute of Applied Physics, Chinese Academy of Science, Shanghai, China

Abstract

The initial Shanghai soft X ray free electron laser (SXFEL) designed shape of the photocathode driver laser is flattop produced by α-BBO stacking. The advantage of this design is attractive to produce electron bunches with low initial emittance and high uniformity along the bunch length. However, some unavoidable modulations are generated along the laser pulse which trigger bunch modulation generated at the source, due to the fast response time (tens of femtosecond) of copper cathode. In order to eliminate the modulations a temporal Gaussian driver laser was designed and tested. Measurement results show the electron bunch longitudinal modulations were removed. In this paper, we present two kinds of driver laser pulse temporal shaping methods based on α-BBO stacking and UV grating pair shaping. Moreover, the corresponding electron bunch temporal profile is also presented.

INTRODUCTION

The drive laser pulse is a crucial component for photoinjectors that produce high density, high brightness electron bunches. The 260 nm UV pulse length required to excite photocathode is around 5~10ps with flattop or Gaussian distribution. Several methods have been explored with pros and cons, such as α-BBO crystal stacking [1-3] and double prism stretcher. Recent research shows that a micro-bunching instability can be induced when illuminating the copper cathode with a laser pulse shaped by α-BBO crystal stacking [4]. This is due to unavoidable modulations generated along laser temporal structure. The copper cathode is very sensitive to the modulated driver laser pulse because its response time is very short (few tens of fs) compared to the periodicity of the modulations of laser longitudinal profile. However, the micro-bunching instability can be significantly reduced if Cesium telluride (Cs_2Te) is used for the photocathode material, because Cs_2Te cathode has a long response time (in a range of a few hundreds of fs to 1 ps). In this case the temporal-modulated laser pulse imprinted on the electron bunch is strongly smoothed out by convolution.

For the case of SXFEL, a copper cathode is used for the photoinjector. In order to reduce the electron bunch micro-bunching instability produced at the source, a temporal Gaussian beam shaped by UV grating pair was developed for the driver laser. In this paper, both α-BBO stacking and ultraviolet (UV) grating pair shaping method are presented and compared, along with a cross-correlator to characterize the temporal UV laser pulse profile.

DRIVER LASER SYSTEM

Figure 1 shows a schematic of the driver laser system which consists 4 stages

1) CW oscillator,
2) Regenerative amplifier,
3) Frequency-tripling stage (266 nm),
4) Laser temporal shaping modulator (Grating pair shaping or α-BBO stacking).

The oscillator (Vitara-T, Coherent Inc.) is driven by a 5 W Verdi (Coherent Inc.) CW pump laser to deliver an 800 nm, 0.7 W beam (79.33 MHz, horizontal polarization) to the Ti:sapphire regenerative amplifier (Spitfire Ace PA, Spectrum Physics Inc.). The pre-amplified pulses (~5 nJ) are first stretched to 200 ps in a grating pair, then amplified to 5 mJ by regen. The output is further amplified to 10 mJ by single-pass amplifier stage. The amplified pulses are then compressed to 2 ps for third harmonic generation (THG).

In the tripler, the 10 mJ pulse is first converted from 800 nm to 400 nm by second harmonic generation in a β-BBO crystal (type I, o + o = e, θ =29.2°) with thickness 0.5 mm, and subsequently sum-frequency generated in a second β-BBO crystal (type I, θ=44.4°) with thickness 0.5 mm. The conversion efficiency from 800 nm to 266.7 nm was about 2%, or a 2 ps UV pulse with ~200 μJ photon beam energy.

For the UV laser temporal shaping part, α-BBO stacking was firstly tested. Starting with the 2 ps input UV pulse, an 11 ps flattop pulse was produced by stacking 8 equivalent pulses. In order to reduce laser pulse temporal modulation generated in the pulse stacking procedure, a UV grating pair shaping was developed to replace the α-BBO stacking stage. With an input ~200 fs UV pulse, an output pulse duration of 5 ps~12 ps could be produced by adjusting the grating pair separation.

As a diagnostic stage, a collinear cross-correlator was developed to scan the temporal UV pulse structure. A short IR ‘scanning’ pulse is taken from the Vitara oscillator for mixing with the UV pulse. A detailed discussion of the SXFEL cross-correlator is described in reference [5].

DRIVER LASER TEMPORAL SHAPING BYα-BBO STACKING

For the pulse stacking system the lengths and relative orientations of the birefringent α-BBO crystals are indicated in Fig. 2. For tuning, the shape of the final profile is controlled by varying the orientation ϕ of the single crystal.

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† liubo@zjlab.org.cn

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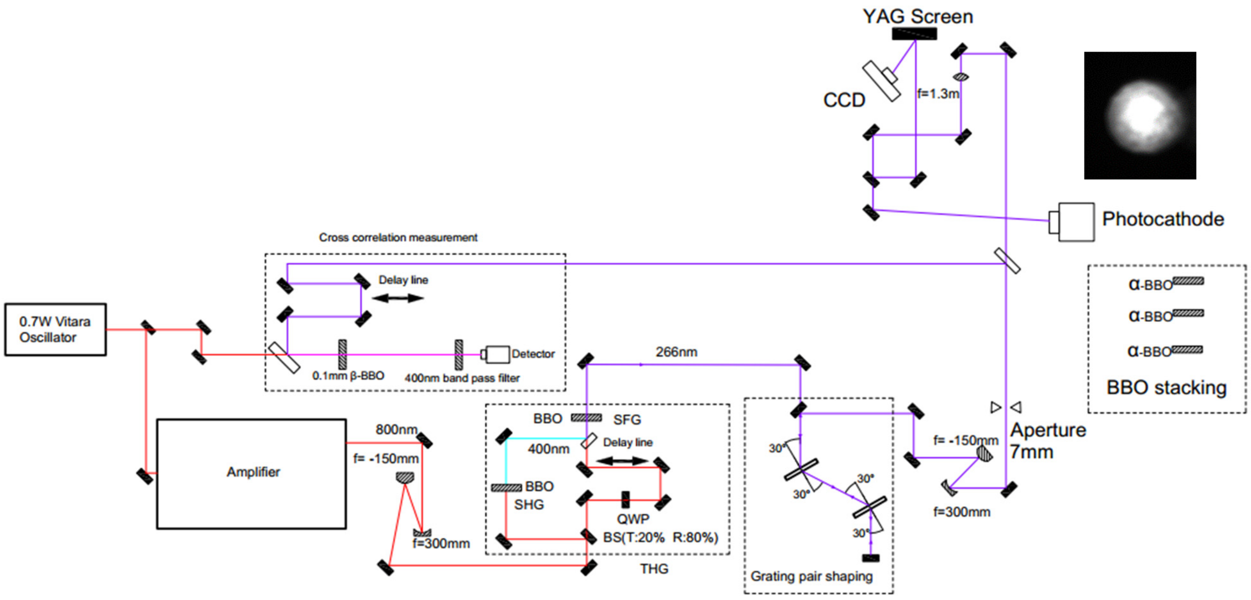


Figure 1: Schematic of SXFEL driver laser system.

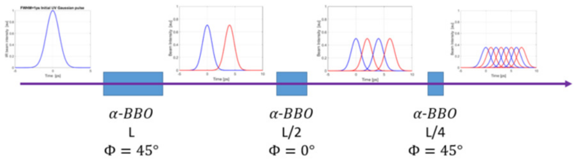


Figure 2: Schematic of α-BBO stacking process.

A brief description of the UV pulse shaping method is presented here with a more detailed description found in reference [1]. α-BBO crystals are anisotropic materials that have different indices of refraction for s, p polarization. Ordinary (o) beam has a polarization perpendicular to the optical axis of crystal, while extraordinary (e) beam has a polarization parallel to the optical axis. For α-BBO crystals, the Sellmeier equations for $n_o(\lambda)$ and $n_e(\lambda)$ are described in reference [3].

The temporal separation (Δt) between o beam and e beam when they propagate through the BBO birefringence crystal is given by Eq. (1).

$$\Delta \mathrm{t} = \mathrm{L} * \mathrm{GVM} \tag{1}$$

Where L is the thickness of crystal and the Group Velocity Mismatch (GVM) is expressed in Eq. (2).

$$\mathrm{GVM} = \frac{1}{V_{ge}} - \frac{1}{V_{go}} \tag{2}$$

V_{ge} is e-ray group velocity and V_{go} is o-ray group velocity which are described in Eq. (3).

$$\mathrm{v_g} = \frac{\mathrm{c}}{\mathrm{n}}\left(1 + \frac{\lambda}{\mathrm{n}}\frac{\mathrm{dn}}{\mathrm{d}\lambda}\right) \tag{3}$$

At $\lambda =$ 266.7 nm we obtain the group refractive index for both o-ray and e-ray, which are n_{go}= 2.08, n_{ge}= 1.8. Therefore, group velocity mismatch (GVM) is 0.93 ps/mm at 266.7 nm [5]. For the pulse stacking process, 3 pieces of α-BBO crystals with thickness L_1 = 5.92 mm, L_2 = 2.96 mm, L_3 = 1.48 mm were used to produce a 10.63 ps flat-top UV pulse from an input pulse duration of 1 ps.

DRIVER LASER TEMPORAL SHAPING BY UV GRATING PAIR

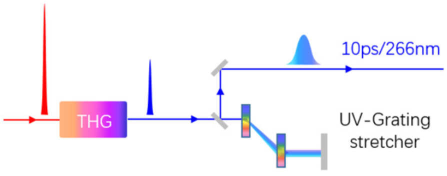


Figure 3: Schematic of grating pair shaping system.

Figure 3 shows the principle of the UV grating stretcher system. The parameters of the Jenoptik manufactured grating pair are listed in Table 1.

Table 1: Parameters of UV Grating Pair

UV grating pair parameters	
Grating lines/mm	3846
Incident angle	30°
Input pulse duration	100 fs
Output pulse duration	10 ps
Grating separation	178 mm
Material	Fused silica

The group delay dispersion (GDD) introduced by the grating pair stretcher is given by Eq. (4).

$$\mathrm{GDD} = \frac{d^2\phi}{d\omega^2} = \frac{m^2\lambda^3 L_g}{2\pi c^2} \times \left[1 - \left(-m\frac{\lambda}{\Lambda} - \sin\theta_i\right)^2\right]^{-3/2} \quad (4)$$

Where m is the diffraction order (usually -1), λ is the center wavelength, L_g is the distance between the two parallel gratings, Λ is the period of the grating, and θ_i is incident angle. This formula shows that the total negative dispersion introduced can be fine-tuned simply by changing the distance between the gratings.

RESULTS AND DISCUSSION

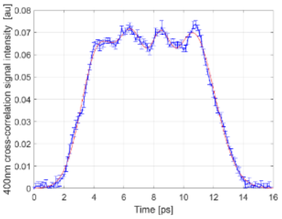
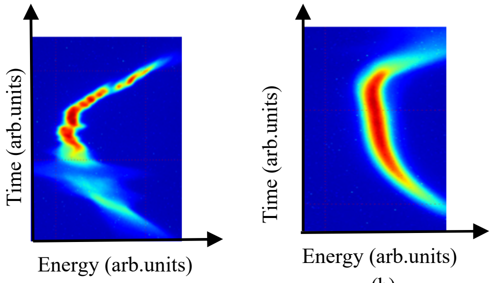


Figure 4: Measurement of 8 stacked pulses using cross correlation.

Figure 4 shows the temporal structure produced using the UV pulse stacking method. The temporal structure is measured by the in-house constructed cross correlator. The pulse width is 10 ps (full width at half maximum, FWHM). An estimated 4.2% modulation was observed in the cross correlation measurement.

The stacked UV pulses were then transported to illuminate the copper cathode. The corresponding electron beam longitudinal phase space at the end of injector are shown in Fig. 5 (a). The modulations along the longitudinal profile of the electron beam are clearly visible. The number of spikes is almost doubled with respect to the number of sub-pulses of the laser profile. This is due to the unavoidable amplitude modulation on the stacked laser temporal profile. The temporal separation between two stacked pulses is limited by the interference pattern generated by the overlap of subsequent replicas of the same polarization state. Therefore, some modulation is produced due to the fact that discrete number of sub-pulses with limited length add up to the final profile.



(a) (b)

Figure 5: Electron beam longitudinal profile measured by transverse deflecting cavity.

In order to eliminate the electron beam modulation, a Gaussian UV pulse with 10.7 ps duration was produced by a grating pair stretcher. The longitudinal profile modulation of electron beam disappears in the arrangement using the temporal Gaussian pulse stretcher Fig. 5 (b). The Gaussian pulse longitudinal distribution shown in Fig. 6 was measured using the same cross-correlator.

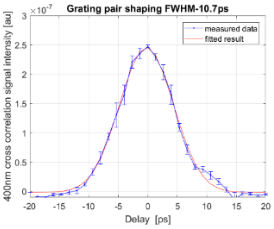


Figure 6: Measurement of stretched UV Gaussian pulse using cross correlation.

CONCLUSION

Two UV laser pulse shaping methods were developed at the SXFEL to producing a longitudinal flattop profile and Gaussian profile, respectively. The flattop pulse generated by the stacking may be not ideal for driving fast-response copper cathodes. In this case, the stretched UV Gaussian pulse is more beneficial for reducing the electron beam longitudinal modulation.

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