Pulse Broadening of Ultraviolet Seed Laser Pulse Width Measurement using Ultrathin β-BBO Crystal*

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Abstract

- XFEL seed laser pulse duration is typically 100 – 200 fs with wavelengths in the 260 nm range.
- The Ultraviolet (UV) pulse width measurement was carried out with intensity cross-correlation.
- The output cross correlation pulse broadened due to group velocity mismatch between the 266.7 nm and 800 nm components. The broadening effect depends on the BBO crystal thickness.
- 0.015 mm, 0.055 mm and 0.1 mm thick BBO crystal samples are explored.
- To the best of our knowledge, this is the first time that β-BBO crystal with thickness of only 0.015 mm has been used to measure the UV seed laser pulse width.
- Experiment results show the measured pulse width broadens with increased BBO thickness in agreement with a theoretical model.

XFEL Seed Laser System

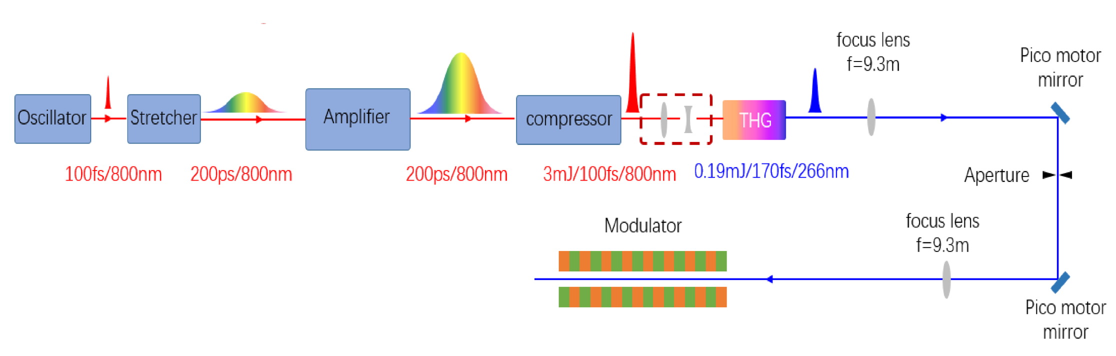

Figure 1: Schematic of SXFEL seed laser system.

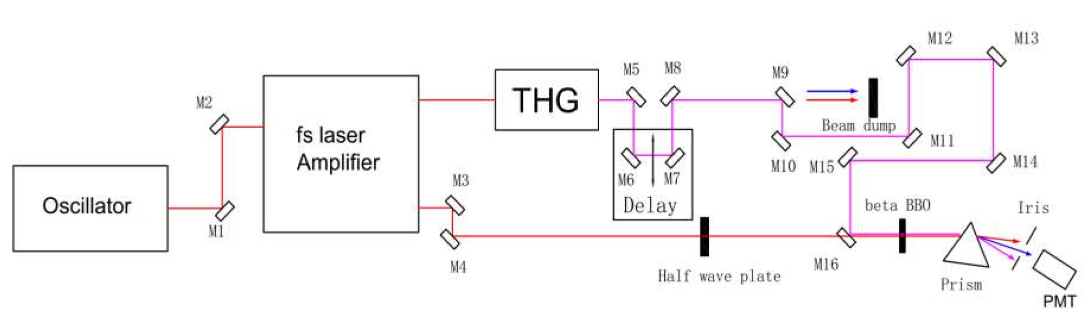

Figure 2: Schematic of the collinear cross-correlation diagnostic system. A prism was used to spatially separate the frequency components at the output stage.

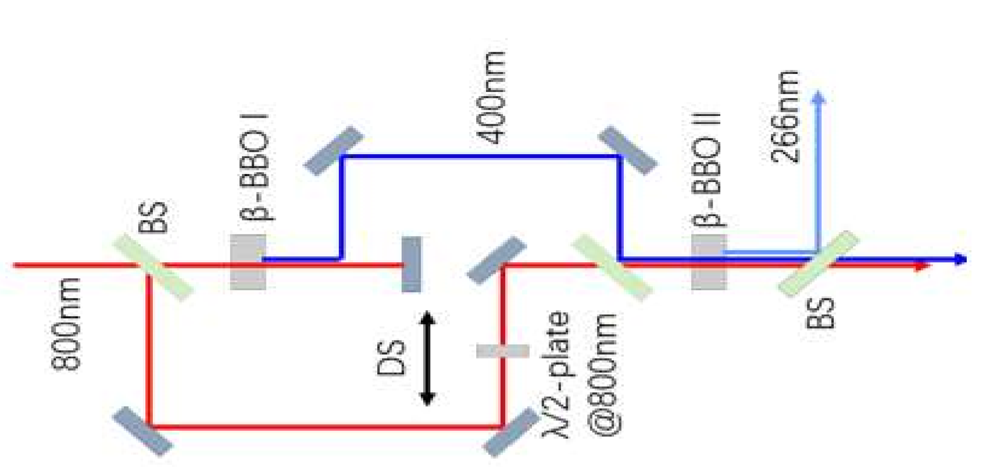

Figure 3: Structure of third harmonic generation (THG) device. BS-beam splitter; DS-delay stage.

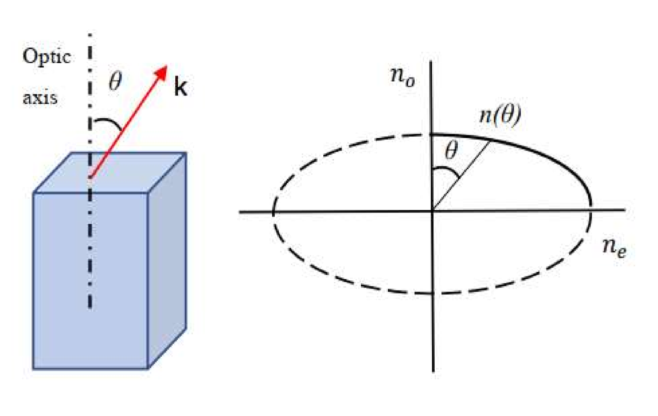

Figure 4: Refractive index $n(\theta)$ of the extraordinary wave. θ is the angle between the optic axis and the direction of propagation. Vector k shows beam propagation direction.

Theoretic Framework For the Cross Correlation Measurement

The frequency and phase matching conditions are expressed in Eqs. (1) and (2) which must be satisfied simultaneously[4].

$$\omega_{IR} + \omega_{DFG} = \omega_{UV} \qquad (1)$$

$$n_{IR}\omega_{IR} + n_{DFG}\omega_{DFG} = n_{UV}\omega_{UV} \qquad (2)$$

For an o-wave $n(\omega) = n_o(\omega)$; for an e wave $n(\omega) = n_e(\theta, \omega)$ also depends on the angle θ between the direction of the wave and the optic axis of the crystal, which is shown in Fig.4. and expressed in Eq.(3) [4].

$$\frac{1}{n_e^2(\theta,\omega)} = \frac{\cos^2\theta}{n_o^2(\omega)} + \frac{\sin^2\theta}{n_e^2(\omega)} \qquad (3)$$

The cross-correlation overlap integral for intensity output can be expressed as Eq. (4).

$$I(\tau)_{cc} = \alpha \int_{-\infty}^{\infty} I_{uv}(t) I_{IR}(t-\tau)dt \qquad (4)$$

Assume pulses with Gaussian distribution along with negligible frequency chirp and negligible group velocity mismatch, the full width at half maximum (FWHM) τ_{cc} of the output envelope is

$$\tau_{cc} = \sqrt{\tau_{IR}^2 + \tau_{UV}^2} \qquad (5)$$

UV input pulse width can be derived by deconvolution according to Eq. (6).

$$I_{cc}(\tau) \approx \int_{-\infty}^{\infty} \left\{\exp\left[-2ln2\left(\frac{t}{\tau_{UV}}\right)^2\right]\right\}^2 \times \left\{exp\left[-2ln2\left(\frac{t-\tau}{\tau_{IR}}\right)^2\right] \otimes sqr\left[\frac{t}{\Delta(v_g^{-1})_{cc} l_c} + \frac{1}{2}\right]\right\}^2 dt \qquad (6)$$

$sqr(x) = \begin{cases} 1, & |x| \le 1/2 \\ 0, & otherwise \end{cases}$, τ_{UV}- UV beam FWHM, τ_{IR}-IR beam FWHM . $\Delta(v_g^{-1})_{cc}$-GVM between the UV and IR beams, l_c-BBO thickness and $\otimes$ denotes convolution.

The expression for group velocity and group velocity mismatch are given by in Eq. (7) and (8), respectively.

$$v_g = \frac{c}{n}\left(1 + \frac{\lambda}{n}\frac{dn}{d\lambda}\right) \qquad (7)$$

$$\Delta(v_g^{-1})_{cc} = GVM = \frac{1}{V_g^{IR\_o}} - \frac{1}{V_g^{UV\_e}} \qquad (8)$$

The refraction indices for a 266.7 nm e-ray propagating through the BBO crystal with a cutting angle $\theta = 44.4°$ were calculated using Eqs. (3), (9) and (10)

$$n_o(\lambda) = \sqrt{2.7405 + \frac{0.0184}{\lambda^2 - 0.0179} - 0.0155\lambda^2} \qquad (9)$$

$$n_e(\lambda) = \sqrt{2.3730 + \frac{0.0128}{\lambda^2 - 0.0156} - 0.0044\lambda^2} \qquad (10)$$

$$\frac{dn_o(\lambda)}{d\lambda} = \frac{1}{2} * \frac{-\frac{0.0184}{(\lambda^2 - 0.0179)^2} * 2\lambda - 0.0155 * 2\lambda}{\sqrt{2.7405 + \frac{0.0184}{\lambda^2 - 0.0179} - 0.0155\lambda^2}}$$

$$\frac{dn_e(\lambda)}{d\lambda} = \frac{1}{2} * \frac{-\frac{0.0128}{(\lambda^2 - 0.0156)^2} * 2\lambda - 0.0044 * 2\lambda}{\sqrt{2.3730 + \frac{0.0128}{\lambda^2 - 0.0156} - 0.0044\lambda^2}}$$

Results and discussion

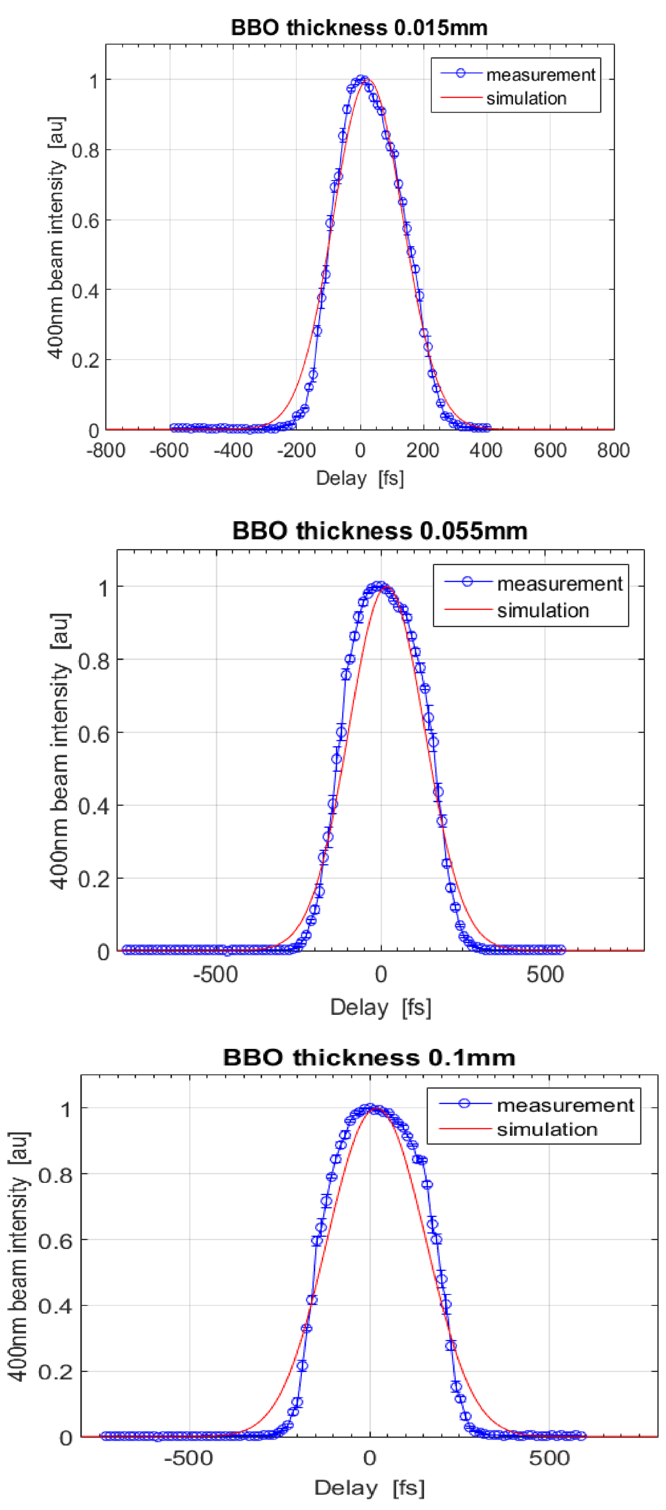

Figure 5: Cross correlation data with error bars (blue line) and numerical fits (red line) using 0.015mm, 0.055mm, and 0.1mm β-BBO crystal for DFG. All curves are fitted by Eq. (6) with τ_{IR}=57 fs, τ_{UV}=248 fs, and $\Delta(v_g^{-1})_{cc}$= 671.5 fs/mm.

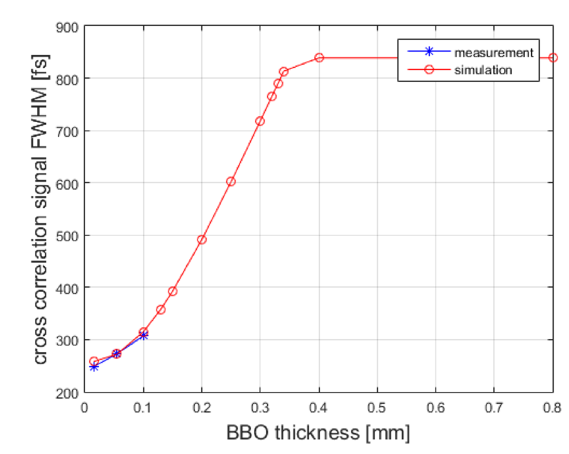

Figure 6: FWHM of cross correlation signal from data in Fig 5. For these data Eq. (6) with τ_{IR}=57 fs, τ_{UV}=248 fs, and $\Delta(v_g^{-1})_{cc}$= 671.5 fs/mm.

Summary

- pulse broadening of the 400 nm DFG cross-correlation signal was investigated in three different β-BBO crystal thicknesses. 0.015mm BBO crystal thickness measurements for the first time to our knowledge.
- The results show that the 400nm DFG pulse width increases as the BBO thickness increases as predicted.
- 0.055 mm crystal the measured ~272 fs FWHM pulse length is in very good agreement with theory and the two other measurements are within a about 4 percent.
- Results agree well with the theoretical model .
- Further study are underway to explore influence from dispersion, spatial chirp and other nonlinear mechanisms.

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Acknowledgments

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