Generation and compression of 10-fs deep ultraviolet pulses at high repetition rate using standard optics: supplement

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1. RAY TRACING OF ACHROMATIC PHASE-MATCHING

Achromatic phase-matching achieves small phase mismatch over a large spectral width by introducing an angular dispersion in the fundamental beam, which—in the ideal case—perfectly matches the phase-matching conditions for type I second harmonic generation (SHG) in the $\beta$-barium borate (BBO) crystal. The angular dispersion is introduced by spatially separating the spectral components of the fundamental beam using a pair of prisms (prism compressor) before focusing the dispersed beam into the BBO crystal with a short-focal-length off-axis parabolic mirror (OAPM).

![Ray tracing simulations of phase-matching](image)

Fig. S1. Ray tracing simulations of phase-matching. (a) Ray tracing geometry and OAPM orientations. (b) Calculated propagation angle inside the BBO crystal as a function of wavelength for both OAPM orientations and phase-matching angle for type I SHG (top). The bottom panel shows the corresponding SHG efficiencies. (c) Calculated SHG efficiency for both OAPM orientations as a function of prism compressor length $L_1$.

We investigated the phase-matching conditions as a function of optical parameters (such as apex-to-apex distance between prisms) by means of ray tracing calculations, which included all relevant components of the optical setup: the incident, collimated beam was dispersed by a sequence of two fused silica prisms with an apex angle of $68.1^\circ$ and a separation $L_1$. After the second prism, the OAPM with effective focal length $f = 20.3$ mm and off-axis angle $\theta = 90^\circ$ focused the spectral components into the BBO crystal (assumed to be cut for SHG at 530 nm). Refraction at the air-BBO interface was taken into account. A schematic of the ray tracing geometry...
is shown in Fig. S1a. We also investigated the impact of two different orientations of the OAPM, labeled “OAPM orientation 1 (2)” in Fig. S1a. In orientation 2, the OAPM is mirrored with respect to the incident beam direction. Orientation 1 was used in our setup, as can be seen in Fig. 1 in the main text.

Results from the ray tracing calculations are presented in Figs. S1b and c. Figure S1b shows phase-matching angle for type I SHG and the propagation angle inside the BBO crystal as a function of wavelength for both OAPM orientations, for a prism-compressor length of $L_1 = 860 \text{ mm}$. Perfect phase matching at 530 nm is assumed such that the curves overlap at that wavelength. Both curves show excellent agreement with the phase-matching angle in the close proximity of 530 nm, but on the whole, OAPM orientation 2 results in better phase matching because the curvature of the angular dispersion approximately follows the ideal phase-matching curve, in contrast to the angular-dispersion curve for OAPM orientation 1. This is also reflected in the SHG efficiency $\text{sinc}^2(\delta)$ (where $\delta = \Delta k L / 2$ is the phase mismatch) which is shown in the bottom panel of Fig. S1b ($L = 100 \mu\text{m}$ is the BBO thickness and $\Delta k = k_{sh} - 2k_f$, with $k_{sh} = 2\pi / \lambda_{sh}$ being the second harmonic wave number and $k_f$ the wave number of the fundamental beam). The difference between the two OAPM configurations arises because the relation between lateral position on the OAPM (direction $d$ indicated in Fig. S1a) and focusing angle is non-linear, so that mirroring the OAPM results in a different shape of the angular dispersion curve.

Figure S1c shows the calculated SHG efficiency as a function of prism-compressor length $L_1$ for both OAPM configurations. In both cases, values for $L_1$ around $\sim 850 \text{ mm}$ give high efficiency in a broad wavelength range, with OAPM orientation 1 generally resulting in narrower efficiency windows due to the effect discussed above.

![Fig. S2. Angular spread inside the BBO for a beam diameter of 2 mm for OAPM orientation 1 (see Fig. S1a) and compressor length $L_1 = 800 \text{ mm}$ obtained from ray tracing calculations.](image)

To investigate the effect of tight focusing on the phase matching, we repeated the ray tracing for an input laser beam with finite beam diameter of 2 mm (corresponds to beam diameter in experimental setup). To this end, the propagation angle inside the BBO was determined for rays at the beam center and edges for each spectral component. This leads to a considerable angular spread for each spectral component at the OAPM focus. The results are shown in Fig. S2 for a prism separation $L_1 = 800 \text{ mm}$. The focusing leads to an angular spread of $\sim 5^\circ$ which relaxes the phase-matching conditions and thus contributes to efficient SHG over an increased spectral range in accordance with the experimental observations.

### 2. VIS NOPA PULSES

Fig. S3 shows an example spectrum of the VIS NOPA pulses used for the DUV generation. We estimated the spectral phase of the uncompressed VIS NOPA pulses at the entrance of the UV generation setup (before prism P1) by numerically evaluating the material dispersion introduced by the optical elements in the beam path, including the dispersion of air. The corresponding pulse duration is 230 fs.
**Fig. S3.** Example VIS output spectrum (black) from the NOPA used for the DUV pulse generation. The spectral phase (red) was calculated from the dispersion introduced inside the NOPA and the propagation to the APM setup.

### 3. CHARACTERIZATION OF NIR REFERENCE PULSE USED FOR THE TG-XFROG

The NIR pulses used as reference pulses in the TG-XFROG measurements were characterized via interferometric SHG-FROG, as shown in Fig. S4.
**Fig. S4.** SHG-FROG characterization of the NIR reference pulse. Top: measured and reconstructed FROG traces. Bottom: temporal (left) and spectral (right) pulse intensity retrieved from the FROG reconstruction.