Arrival-timing diagnostics for pump-probe experiments in SACLA, using X-ray-induced optical transparency in GaAs

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Abstract: We have developed an arrival-timing monitor between XFEL and optical laser pulses in SACLA by using X-ray-induced optical transparency in GaAs. We have evaluated the timing jitter to be 130 fs with 10 fs resolution.
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1. Introduction

X-ray Free electron lasers (XFELs), such as Linac Coherent Light Source (LCLS) [1] and SPring-8 Angstrom Compact free-electron LAser (SACLA) [2], are promising sources of femtosecond X-ray pulses for investigating ultrafast dynamics of chemical reactions, phase transitions, electronic and structural changes with femtosecond time scale, combined with femtosecond optical lasers based on pump-probe technique. Although these optical lasers are synchronized to RF signal of the XFEL accelerator via a phase-locking system, some error sources produce a timing jitter between XFEL and optical laser pulses, which imposes a limitation of time resolution in pump-probe experiments. Recently, sub-10 fs resolution has been achieved using a *post-process* sorting method with an arrival-timing monitor applying transient optical changes of transmittance in Si_3N_4 [3] and reflectance [4] under Soft X-ray FEL excitation at LCLS.

In this paper, we report an arrival-timing monitor using hard X-ray induced transparency in GaAs for pump-probe experiments in SACLA. SACLA is producing hard X-ray pulses with a pulse energy of several hundreds micro-joule, a photon energy range from 4.5 to 12 keV, and a pulse duration of 10 fs at 60-Hz repetition rate [2, 4]. When considering a deeper penetration depth of hard X-rays, a transparent geometry, rather than a reflection scheme, is suitable. We employed GaAs, which has a bandgap in a 850 - 900 nm wavelength region, for the arrival-timing monitor. Excitation of intense X-ray pulse to GaAs enhances its optical transparency, which is caused from an increased bandgap driven by the high-density carriers created in the conduction band. Since NIR light with a photon energy just above the bandgap is strongly absorbed in GaAs without X-ray irradiation, we could expect high-contrast measurement in cross-correlation measurement in an ultrafast time scale. .

2. Experiment

The experimental setup is illustrated in Fig. 1. A 20-μm-thick GaAs film mounted on a 0.5-mm-thick sapphire plate was set under an angle of 45° to the XFEL beam direction. We used 10% of full energy from SACLA, which was estimated to be 20-μJ pulse energy, with 10-keV photon energy for excitation of GaAs. We focused the XFEL beam vertically to 0.01 (vertical) × 0.6 (horizontal) -mm^2 region on the GaAs film with elliptical mirror. ~10-mm diameter beam of the synchronized optical NIR laser was directed in normal to the GaAs surface. The transparent

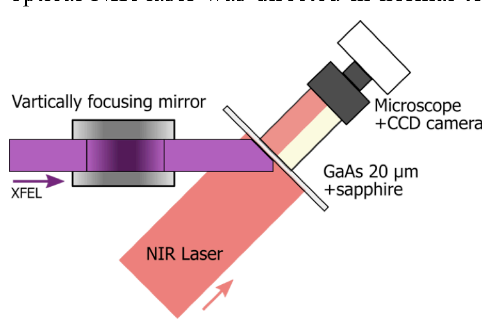

Fig. 1, Top view of the experimental setup for the arrival-timing monitor

images on the surface were captured with a long-distance microscope on a CCD camera on a shot-by-shot basis. We estimated the time window and the resolution to be 2 ps and 10 fs respectively taking into account the geometry of the experiment and the spatial resolution of the microscope.

The NIR laser, which was based on Ti:sapphire chirped pulse amplification system, was provided 4-mJ pulses with 800-nm central wavelength and 30-fs pulse duration at 1 kHz. We divided these pulses to 30 Hz that was the repetition rate of the XFEL operation. Pulse energy of 1% from the NIR laser was used for probing the transparency. We synchronized the NIR laser to the XFEL with a control loop system adjusting the oscillator cavity length to match the repetition frequency to the SACLA master RF signal.

3. Result and discussion

Figure 2(a) shows a single shot image of the transmitted beam of the NIR laser on the GaAs film. The area irradiated with the XFEL beam was extracted clearly by subtracting the background. The drastic change of transparency in the left part of the area (shown in the circle in Fig. 2(a)) indicates the arrival timing of the XFEL beam at the NIR laser arriving. The vertical projections of these consecutive images are traced as the function of relative timing, which is calibrated by scanning the delay stage of the NIR laser, in Fig. 2(b). Variations of these edges were caused by fluctuations of the relative arrival timing between XFEL and the NIR laser. We analyzed the timing jitter in 130 fs root-mean-squire (rms) from the histogram of the arrival timing, which was built from 1000 shots, in Fig. 2(c).

Based on this scheme, we are developing a permanent system in the beamline of SACLA. A beam splitting system [6,7] is used for performing timing diagnostics in parallel to experiments.

4. Conclusion

We have demonstrated that the GaAs-based timing monitor is useful for observation of the timing jitter between the XFEL and the optical NIR laser pulse. This arrival-timing monitor has achieved 10-fs resolution with 2-ps time window. The timing jitter was evaluated to be 130-fs in rms.

5. References

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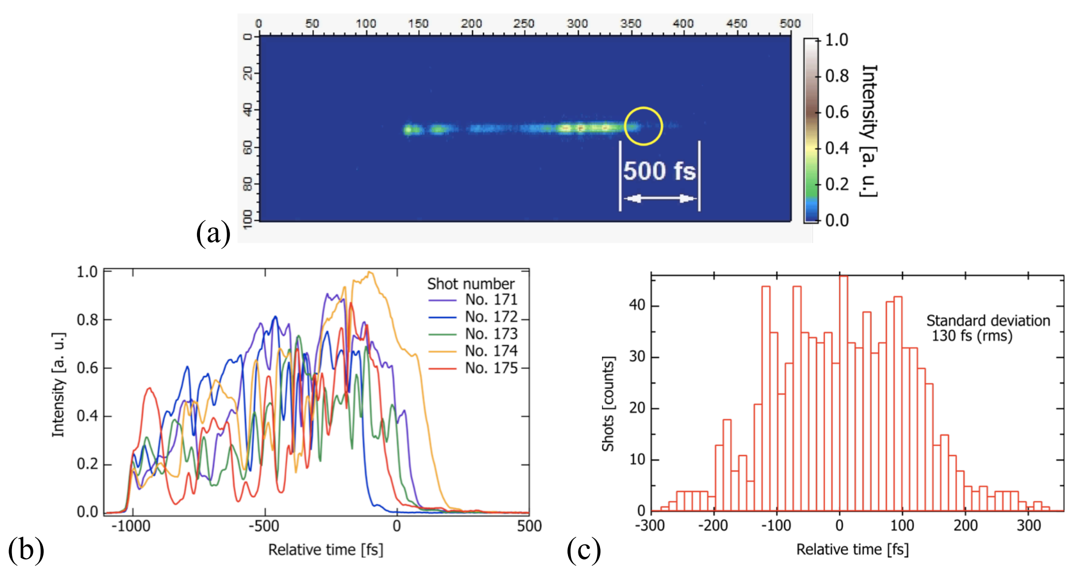

Fig. 2, (a) Transparent image of the NIR laser in the area irradiated with the XFEL beam. (b) Vertical projections of the consecutive images of (a). (c) Histogram of the arrival timing. Standard deviation was 130 fs (rms).