Highly efficient arrival time diagnostics for SACLA

A pump and probe technique combining XFELs and ultrafast optical lasers is a powerful approach for investigating the dynamics of phase transitions, shock compression, and charge transfer with ultrahigh spatio-temporal resolution.

The time resolution in pump and probe experiments is determined by the pulse widths of the pump and probe beams and the accuracy of the timing difference between the pump and probe pulses (Fig. 1). SACLA is able to generate X-ray pulses with a pulse width of less than 10 femtoseconds, which fixes the ultimate temporal resolution. However, the time resolution in pump and probe experiments can be degraded by timing instabilities, including short-term jitters and long-term drifts, between the pump and probe pulses, which may originate from the phase jitter of an electron bunch at the accelerator radio frequency (RF), a change in the SASE lasing part in an electron bunch, imperfect synchronization between the optical laser and the RF signal, and vibration of the optical transport channel. Typical values of the timing jitter are on the order of 100 fs, which is much larger than the pulse duration of SACLA.

To improve the time resolution in pump and probe experiments, a scheme based on a post-process analysis combined with arrival time diagnostics has been proposed. Several methods, such as a THz streak and a change in optical reflectivity/transmission, have recently been developed at XFEL facilities. In the hard X-ray region, changes in the optical transmittance of materials excited with XFEL pulses have been utilized for timing diagnostics at LCLS [1]. In this case, large pulse energy of X-rays on the order of millijoule has been employed due to the weak interaction between matter and hard X-rays. SACLA generates

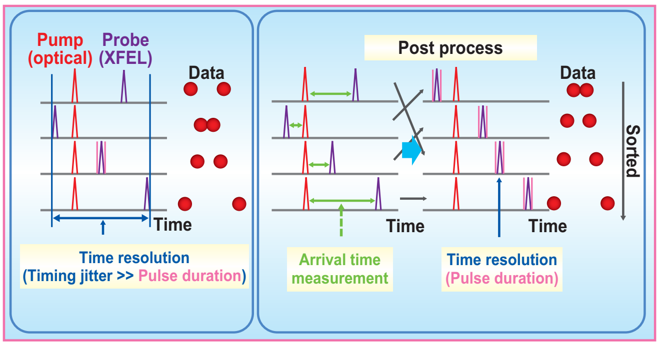

Fig. 1. Schematic images of the time resolution in a pump and probe experiment. **(a)** Time resolution including timing jitter. **(b)** Time resolution improved by post process technique with arrival time diagnostics.

a moderate pulse energy with shorter wavelengths that has weaker interactions. We thus needed to develop a technique with higher efficiency .

For this purpose, we developed arrival time diagnostics combining a spatial decoding technique and a one-dimensional focusing mirror, which was utilized to increase the intensity of an X-ray [2]. The spatial decoding technique was applied to convert the arrival time of an X-ray pulse into spatial distribution. Since the spatial decoding technique is affected by the spatial intensity modulation of the X-ray profile, we utilized a high-quality mirror developed by an elastic emission machining (EEM) technique.

We performed an experiment at beamline **BL3** of SACLA (photon energy of 12 keV, pulse energy of 12 ± 2 μJ). We used a GaAs wafer as a target. When intense X-rays are irradiated to the GaAs, a number of electron-hole pairs are generated. This, which causes modulation of the band structure and changes of the absorption coefficient of an optical laser with a photon energy larger than the band gap (1.43 eV). We are able to retrieve the timing information from a spatially modulated transmission profile of the optical laser.

Figures 2(a), 2(b), and (2c) show the typical single-shot spatial profiles of the transmitted laser pulse under an intense XFEL pulse, which originate from the changes in optical transmission. The temporal overlap information is projected in the horizontal direction. The lower axis corresponds to the horizontal pixel number while the upper axis represents the time Δt determined from the geometry. A larger Δt indicates the earlier arrival of an X-ray pulse relative to the optical laser pulse. Figure 2(a) shows the profile measured without the temporal overlap, where the timing of the optical laser was 2 ps in advance of that of the XFEL pulse. In this case, the optical laser pulse is mostly absorbed by the GaAs. Figure 2(b) shows the profile with temporal overlap, which causes a change in the optical transmission. The right edge of the bright spot corresponds to the onset of the temporal overlap between these pulses. Figure 2(c) shows the profile without temporal overlap, where the timing of the optical laser was 2 ps after XFEL irradiation. Both edges of the profile originating from a slit show the timing window of this arrival time monitor.

In order to evaluate the temporal jitter between XFEL pulse from SACLA and the optical laser pulse, we performed a measurement with this system. Figure 3(a) shows the arrival timings of each pulse , plotted over 1000 shots. The positional change of the

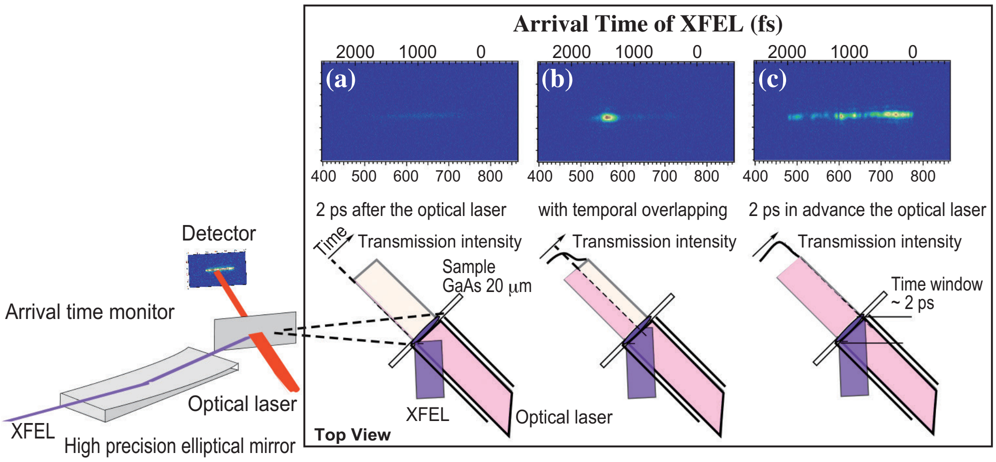

Fig. 2. Schematic image of the spatial decoding technique and typical profiles of optical laser pulses with X-ray pulse irradiation. **(a)** 2 ps after the optical laser. **(b)** With temporal overlapping. **(c)** 2 ps in advance of the optical laser.

right edge corresponds to the timing jitter. From these results, we obtained a distribution of the arrival time (Fig. 3(b)) and determined the temporal jitter in this period (100 s) to be 110 fs in RMS.

The timing diagnostics should be performed in parallel with user experiments to compensate for timing jitter using a post-process technique. The pulse energy to be required for our scheme is only around 10 μJ at 10 keV, which is less than 3% of total pulse energy of SACLA. Although the present method is in a destructive scheme, our highly efficient method allows simultaneous measurements to be performed, if we extract a small fraction of the X-ray pulse energy to a dedicated branch for the timing diagnostics. For this purpose, we are developing an X-ray diagnostic branch with an X-ray transmission grating [3], which will provide information on the arrival time at each shot.

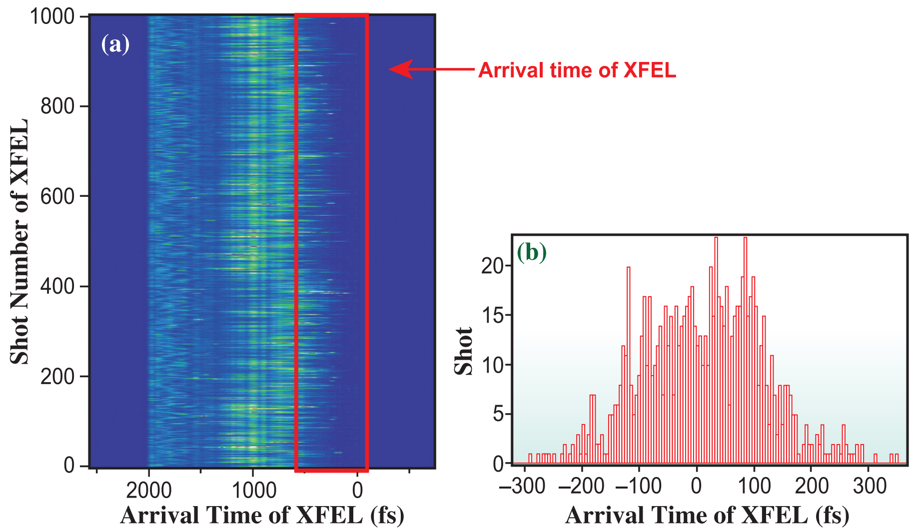

Fig. 3. **(a)** Change in transmission intensity profile for 1000 shots. The vertical axis indicates the shot number of the XFEL while the horizontal axis shows the relative arrival time. **(b)** Histogram of the measured arrival time obtained from (a). [2]

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