SACLA
New Apparatus, Upgrades & Methodology

To realize the unique potential of SACLA to lead with innovations in science and industrial applications requires the on-going development of experimental methods and instruments. In 2013, we continued to improve X-ray optics, diagnostics, detectors, and experimental instruments. In this section, we introduce two achievements in X-ray optics and methodology.

1) Generation of an intense 50-nm X-ray spot with a two-stage focusing system

The brilliant, coherent, and femtosecond X-ray pulses from SACLA provide an unprecedented opportunity to generate an extremely intense X-ray beams by applying a proper focusing system. In collaboration with a team led by Prof. Kazuto Yamauchi of Osaka University, we successfully produced state-of-the-art X-ray mirror optics that have a very high efficiency without distorting wavefronts. These technologies were leveraged to construct a 1-μm focusing system at SACLA [1], enabling us to achieve a high intensity level of 10^{18} W/cm^2. This intensity level triggers the generation of X-ray multi-photon processes and nonlinear phenomena. Some of these findings [2,3] are reported in this volume.

If we could increase the intensity by two-orders of magnitude, we would reach a new regime that is governed mainly by nonlinear interactions. To achieve this, we developed a new focusing system at SACLA (Fig. 1). A unique point of the design is to use a pair of focusing systems, both in the Kirkpatrick-Baez geometries, which are placed with a separation of approximately 70 m. The first system is used to expand the beam size at the second system, while the second system enables the generation of an extremely small spot while keeping a large working distance between the last mirror and the sample point. With the two-stage focusing system, we generated a 50-nm focused X-ray beam with an extreme intensity of 10^{20} W/cm^2 [4]. The high intensity was utilized to observe the two-photon absorption phenomenon in the hard X-ray range [5]. This system offers an excellent opportunity to investigate X-ray quantum optics, high-energy density science, and even high-energy physics, such as an evaluation of the QED framework.

2) Dispersive X-ray absorption spectroscopy with grating beam splitter

Intense SASE-XFEL light with a reasonable bandwidth (~50 eV at 10 keV) is suitable for conducting dispersive spectroscopy that enables single-shot detection in a wide spectral region. However, a stochastic spike structure in the frequency (and temporal) domain can complicate analysis, especially when conducting a normalizing

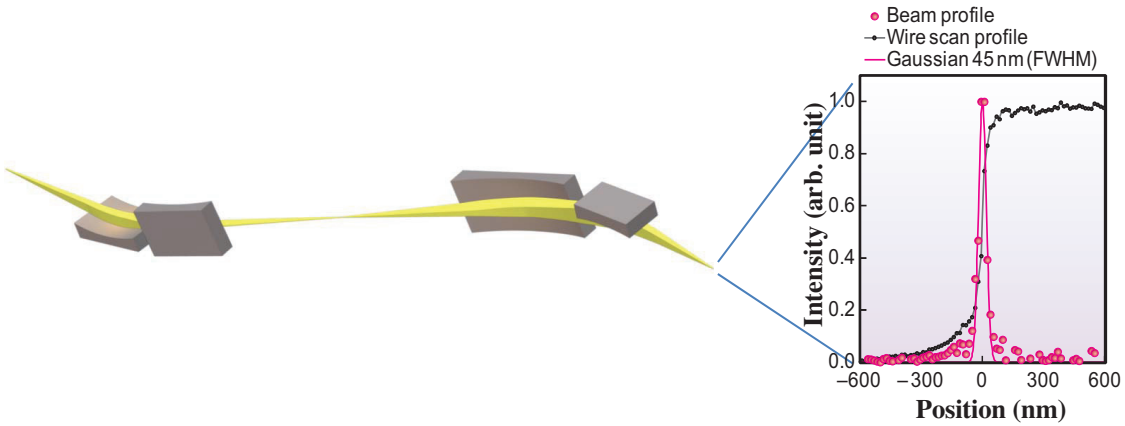

Fig. 1. Schematic view of a two-stage focusing system and a vertical beam profile at a focus measured using the knife-edge scanning method.

procedure. To address this challenge, we developed a new scheme that combines our single-shot dispersive spectrometer [6] with a grating beam splitter, as shown in Fig. 2. With this approach, we could produce a pair of nearly identical replica of spectrographs. By inserting a sample in one of the branches, we could measure a differential dispersive spectrum. Since we could simultaneously measure a wide range of spectrum without scanning a monochromator, this method proved highly useful for advanced research in the field of ultrafast chemistry by performing pump-probe measurements in combination with optical lasers. As a first step, we successfully performed a proof-of-principle experiment with zinc foil [7]. We then applied the method to time-resolve absorption spectroscopy. We measured the differential spectra of the Fe(III)$(C_2O_4)_3^{3-}$ complex around the K-edge of the Fe atom at several pump-probe time delays and observed a rise time of 260 ± 50 fs [8]. Our results open up the possibility of using time-resolved X-ray spectroscopy to observe transient phenomena at the femtosecond time scale. Exciting research in the future will reveal transient dynamics of chemical reactions at an atomic scale with a very short timescale at femto- and atto-second levels.

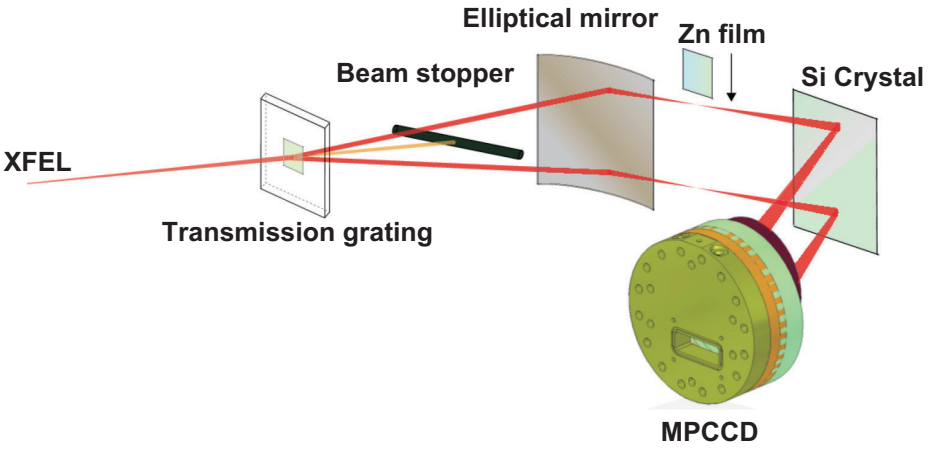

Fig. 2. Schematic setup for dispersive X-ray absorption spectroscopy using a grating beam splitter.

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References

[1] K. Yumoto *et al.*: Nature Photon. **7** (2013) 43.
[2] H. Fukuzawa *et al.*: Phys. Rev. Lett. **110** (2013) 173005.
[3] K. Tamasaku *et al.*: Phys. Rev. Lett. **111** (2013) 043001.
[4] H. Mimura *et al.*: Nature Commun. **5** (2014) 3539.
[5] K. Tamasaku *et al.*: Nature Photon. **8** (2014) 313.
[6] Y. Inubushi *et al.*: Phys. Rev. Lett. **109** (2012) 144801.
[7] T. Katayama *et al.*: Appl. Phys. Lett. **103** (2013) 131105.
[8] Y. Obara *et al.*: Opt. Exp. **22** (2014) 1105.