Platforms for XFEL experiments with high-power optical lasers

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Summary

- Two types of high-power laser systems are available at SACLA with designated experimental chambers for each.
- The high-power nanosecond laser with energies around 15 J on sample can be used in EH5. It is mainly used for studies of matter under high-pressure or of hydrodynamics such as plasma instabilities.
- The high-power femtosecond laser with focused peak intensities over 10^{19} W/cm^2 is used in EH6 to study the very fast dynamics of laser irradiated matter, such as heating or ionization.
- In recent years, the digital technologies have been implemented for stable operation by monitoring the system status of high-power lasers.

Overview of two experimental platforms with high-power lasers

High-power nanosecond laser at EH5 on BL3

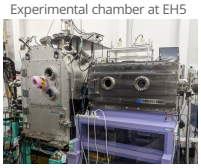
"Dynamic compression"

High-power nanosecond laser	
Pulse energy	>15 J on sample
Pulse shape	5 ns quasi-square
Spot size	140/180/260/470 um FWHM
Wavelength	532 nm
Rep. rate	0.1Hz
Shot rate	1 shot / 3–10 min.

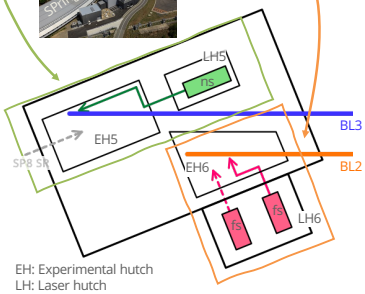
XFEL (Beamline 3)	
Photon energy	4-22 keV
Band width, ΔE/E	Pink: ~3 x 10^{-3} Seeded: ~3 x 10^{-4} Monochromatic: 1.3 x 10^{-4}
Pulse energy	Pink: ~700 μJ @10keV
Pulse duration	<10 fs
Rep. rate	30 Hz
Focusing optics	KB mirror (Down to 0.5 μm from 600 μm unfocused beam)
Advanced operation	Self-seeding Two color Split-and-delay optics

Nanosecond Laser

Experimental chamber at EH5



SACLA - SPring-8 Experimental facility



EH: Experimental hutch
LH: Laser hutch

High-power femtosecond laser at EH6 on BL2

"High energy density science"

Femtosecond Laser

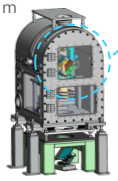
Experimental chamber at EH6

High-power femtosecond laser	
Pulse energy	~8 J
Pulse duration	~30 fs (typ.)
Spot size	15-20 μm (typ.)
Wavelength	800 nm
Rep. rate	1Hz
Shot rate	1 shot / 3-5 min.
Timing jitter	~30 fs@RMS / 3 min.
Timing drift	+/- 500 fs / day

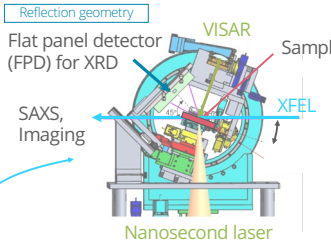
XFEL (Beamline 2)	
Photon energy	4–22 keV
Band width, ΔE/E	Pink: ~3 x 10^{-3} Monochromatic: 1.3 x 10^{-4}
Pulse energy	Pink: ~500 μJ@10 keV
Pulse duration	<10 fs
Rep. rate	30 Hz
Focusing optics	CRLs for focus (~a few μm) Mirror for 1D focus (~a few um in vertical)

Platform with high-power nanosecond laser in EH5

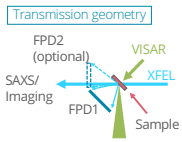
Experimental chamber has designed for efficient measurements of X-ray diffraction (XRD), X-ray imaging(XI), and small-angle X-ray scattering (SAXS)



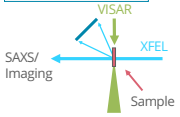
Reflection geometry



Transmission geometry



Side-on geometry

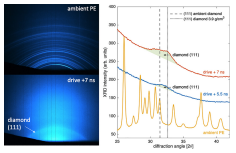


[Recent Updates]
Up to 3 FPDs can be used at once.

[Recent Updates]
VISAR can be used in side-on geometry by replacing single component.

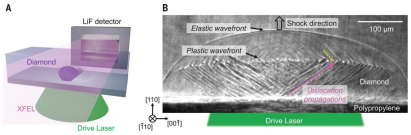
Measurement examples

X-ray diffraction — Dissociation of hydrocarbon implied by diamond formation



D. Kraus et al., *Phys. Rev. Res.* **5**, L022023 (2023)

X-ray imaging — Visualized the motion of ultrafast dislocation in diamond



K. Katagiri et al., *Science* **382**, 69 (2023)

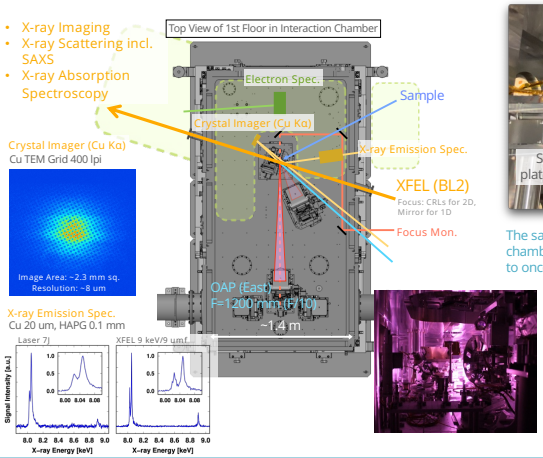
Ongoing Developments

- ❑ Improve laser stability
  - ○ Due to the temperature control difficulties in the laser hutch, the laser energy varies in time during the experiments.
  - ○ The temperature stability is expected to be improved by modifying the laser operation scheme.
  - ○ In collaboration with Osaka University, the operation scheme of laser power supply will be modified to minimize the temperature increase. The new scheme will be tested in early FY2025.
- ❑ Improvement of data handling
  - ○ The data recorded with standalone cameras, such as FPD, are now copied to a user directory on HPC for better accessibility.
  - ○ The file transfer scheme will be modified in near future to improve the reliability.

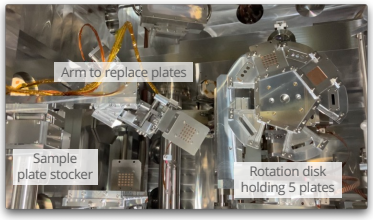
Platform with high-power femtosecond laser in EH6

Basic instruments regularly monitor laser-matter interactions along with XFEL measurements

- X-ray Imaging
- X-ray Scattering incl. SAXS
- X-ray Absorption Spectroscopy



[Recent Updates] Sample changing system in vacuum has been utilized in user experiments from 2024B

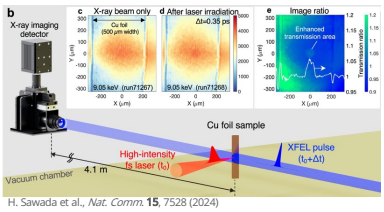


The sample changing system helped to reduce the number of chamber openings for sample replacement; from every night to once per 3 days (i.e. 4 times to once for typical beamtime).

- Before the utilization of sample changing system, sample replacement required several hours due to vacuum pumping and the related realignment of the experimental system.
- The newly developed in-vacuum sample changer features a capacity for:
  - 20 sample plates stored within the in-side-the-chamber stocker.
  - 5 sample plates on the rotating disk (should be empty initially).

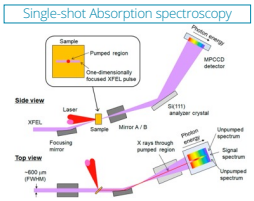
Various techniques have been developed and demonstrated at SACLA to diagnose matter under high-energy-density states

X-ray imaging with near absorption edge — Fast isochoric heating (ionization) in matter



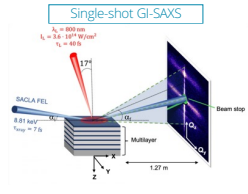
H. Sawada et al., *Nat. Comm.* **15**, 7528 (2024)

Single-shot Absorption spectroscopy



Y. Inubushi et al., *Rev. Sci. Instrum.* **92**, 053534 (2021)

Single-shot GI-SAXS



L. Randolph et al., *Phys. Rev. Res.* **4**, 033038 (2022)