Experimental platforms with high-power lasers at SACLA

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Summary

- Two distinct experimental platforms for combinative use of high-power nanosecond and femtosecond lasers with an XFEL are available at SACLA.
- The nanosecond laser platform is dedicated to exploring the states of dynamically compressed matter, utilizing X-ray diffraction, imaging, and small-angle scattering.
- The nanosecond laser with improved shot-to-shot stabilities has been open to users since FY2023, and further laser improvements are ongoing.
- Various techniques have been developed and demonstrated at SACLA to diagnose matter under high-energy-density states at the femtosecond laser platform.
- A newly developed in-vacuum sample changer for the femtosecond laser platform is expected to significantly improve the efficiency of experimental workflows.

Overview of two experimental platforms with high-power lasers

High-power nanosecond laser at EH5 on BL3

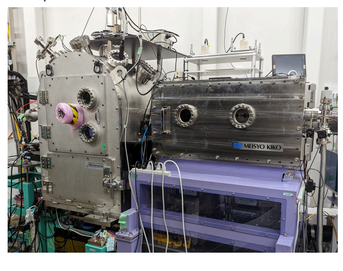
"Dynamic compression"

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.

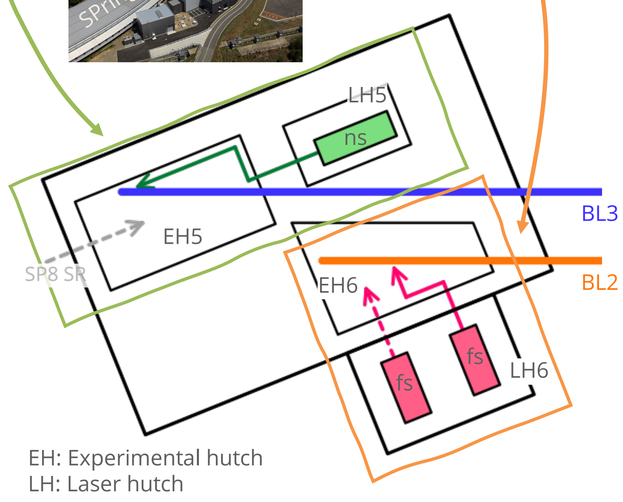
XFEL (Beamline 3)	
Photon energy	4-22 keV
Band width, ΔE/E	Pink: ~3 x 10^{-3} Seeded: ~3 x 10^{-4} Monochromatic: 1.3 x 10^{-4}
Pulse energy	Pink: ~700 μJ @10keV
Pulse duration	<10 fs
Rep. rate	30 Hz
Focusing optics	KB mirror (Down to 0.5 μm from 600 μm unfocused beam)
Advanced operation	Self-seeding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

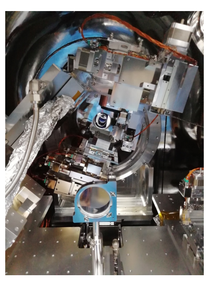
Experimental chamber at EH6

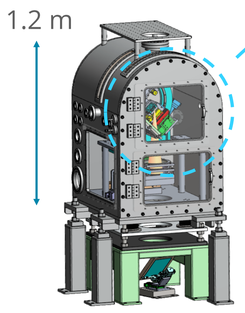
High-power femtosecond laser	
Pulse energy	~8 J
Pulse duration	~30 fs (typ.)
Spot size	15-20 μm (typ.)
Wavelength	800 nm
Rep. rate	1Hz
Shot rate	1 shot / 3-5 min.
Timing jitter	~30 fs@RMS / 3 min.
Timing drift	+/- 500 fs / day

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)

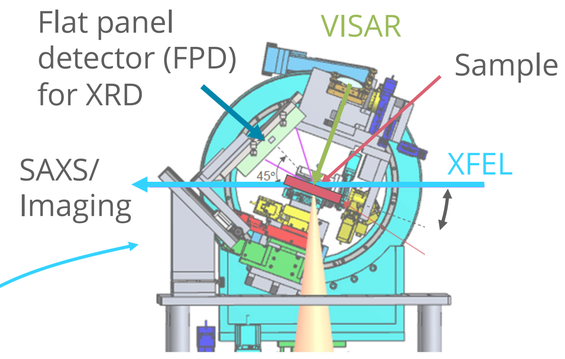
Platform for dynamic compression with high-power nanosecond laser

The experimental chamber is designed for X-ray diffraction (XRD), X-ray imaging(XI), and small-angle X-ray scattering (SAXS)

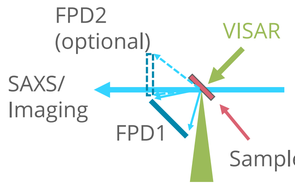




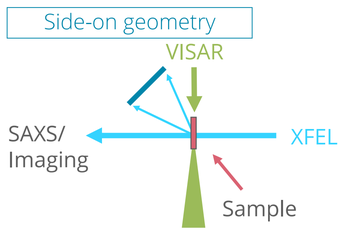
Reflection geometry



Transmission geometry

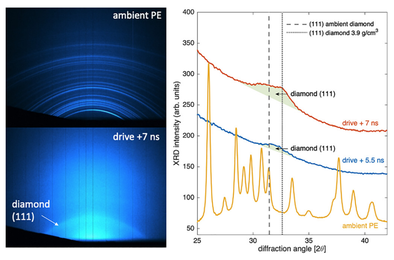


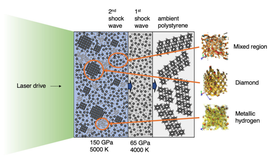
Side-on geometry



Measurement examples

X-ray diffraction Dissociation of hydrocarbon implied by diamond formation

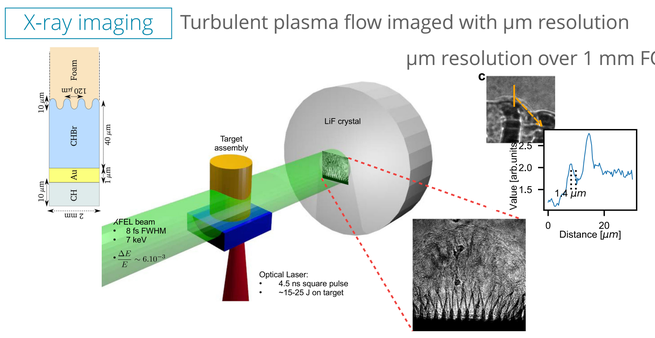




D. Kraus et al., *Phys. Rev. Res.* **5**, L022023 (2023)

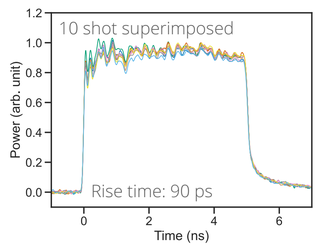
X-ray imaging Turbulent plasma flow imaged with μm resolution

μm resolution over 1 mm FOV



G. Rigon, *Physical Review E*, 100(2), 021201 (2019).
G. Rigon et. al., *Nat. Commun.* 12, 2679 (2021).

[Update] The ns laser with improved shot-to-shot stabilities has been open to users since FY2023



- 1.6 % (std. dev.) in peak power
- 1.3 % (std. dev.) in pulse energy

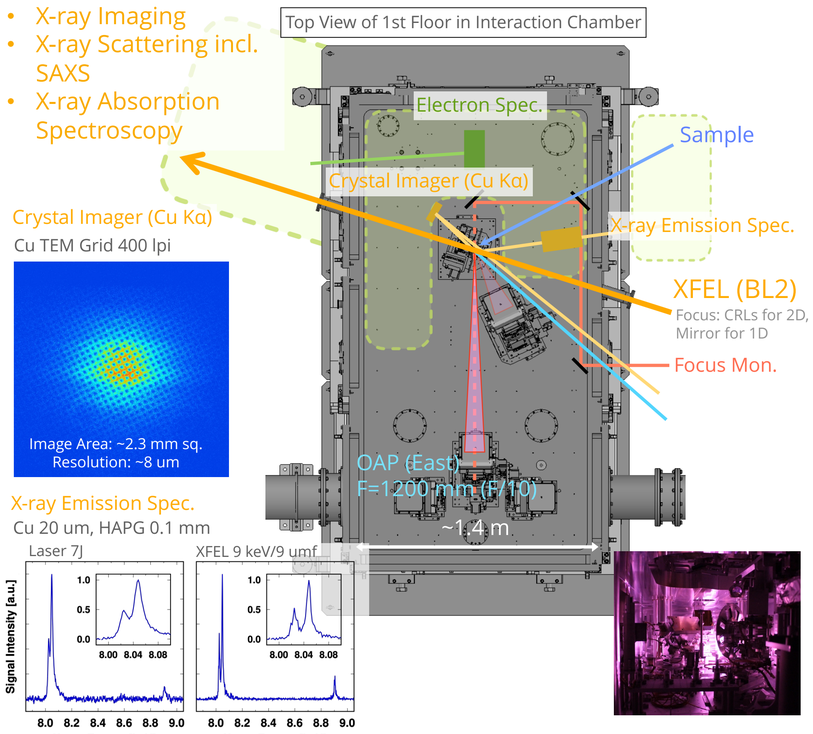
Further laser improvements are ongoing with Osaka University

- ❑ Arbitrary wave generation up to 20 ns
  - Currently, only a 5 ns square pulse is available for users' experiments.
  - Future work will primarily focus on generating square pulses with extended durations and step pulses.
- ❑ Control of energy drift
  - The laser energy drifts by 10% in 48 hours due to thermal instability.
  - Our current objective is to establish energy drift control measures in FY2024.

Platform for High-energy density science with high-power femtosecond laser

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

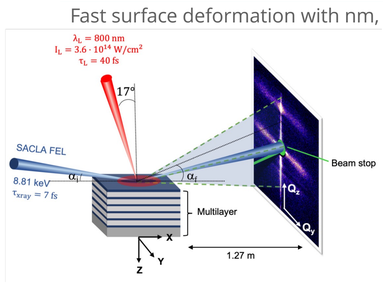
- X-ray Imaging
- X-ray Scattering incl. SAXS
- X-ray Absorption Spectroscopy

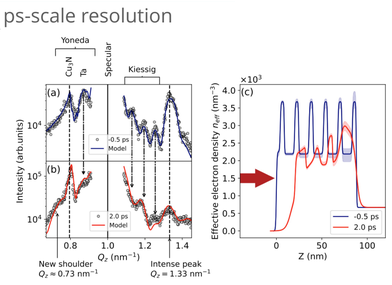


Various techniques have been developed and demonstrated at SACLA to diagnose matter under high-energy-density states

Grazing-Incidence Small-Angle X-ray Scattering (GISAXS)

Fast surface deformation with nm, ps-scale resolution

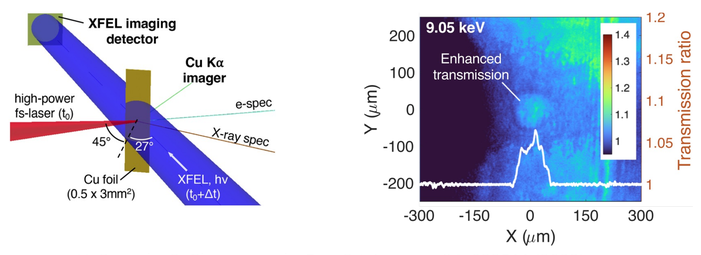




L. Randolph, M. Nakatsutsumi et al., *Phys. Rev. Res.* **4**, 033038 (2022)

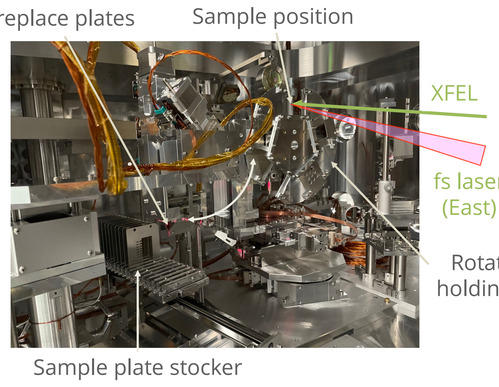
X-ray imaging with near absorption edge

Fast isochoric heating (ionization) in matter



H. Sawada, S. Glenzer et al., *Rev. Sci. Instrum.* **94**, 033511 (2023)

[Update] A newly developed sample changer enables quick sample replacement without breaking the vacuum in the chamber



- Sample replacement currently requires several hours due to vacuum pumping and the related realignment of the experimental system.
- An in-vacuum sample changer is anticipated to streamline experimental workflows significantly.
- 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).
- The time required to replace a single sample plate is approximately 5 minutes.
- The sample changer is projected to be operational in Fiscal Year 2024.

Currently, we can mount 6 plates in the chamber for a day's operation. Consequently, a capacity of 20 plates should suffice for a few days of data collection.