Examples of FLASH user experiments in 2008

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Let me apologize for many missing transparencies which I had to take out in order not to endanger the publishing process of the presented data.
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- Intro: X-ray sources in research
- Research Highlights from FLASH
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X-ray sources in research

X-ray tubes

Synchrotron Radiation sources

X-ray FELs
From X-ray tubes to X-ray FELs

classical "X-ray"

crystal structure analysis with atomic resolution
+ information about femtosecond dynamics
"more light": What is it good for?

High Intensity:
diluted samples,
e.g spectroscopy on mass selected clusters in gas phase,
highly charged ions or
single molecule diffraction

Power Density:
focused to $1 \mu m^2 > 10^{16} \text{ W/cm}^2 \Rightarrow$ nonlinear effects,
plasma physics

Short Pulses:
Excitation $\leq$ timescale of molecular vibrations,
electronic relaxation, ...
$\Rightarrow$ Study of time dependent processes
($pump$ $and$ $probe$ - experiments)
Research Highlights from FLASH
Research Areas

• Femtosecond time-resolved experiments
  - synchronisation FEL - optical laser
  - pump-probe experiments on atoms and molecules
  - sum-frequency generation

• Interaction of ultra-intense XUV pulses with matter
  - multiphoton excitation of atoms, molecules, clusters...
  - creation and characterisation of dense plasmas
  - imaging of biological samples

• Investigation of extremely dilute samples
  - photodissociation of molecular ions
  - highly charged ions
  - mass selected clusters

• Investigation of surfaces and solids
  - XUV laser desorption
  - surface dynamics
  - luminescence under FEL radiation
  - meV-resolution photon and photoelectron spectroscopy of surfaces and solids with nm resolution
FLASH experimental hall
Research examples

- FIR – XUV pump probe / “Streak Camera” (U. Frühling et al.)
- Single shot diffraction imaging (Chapman, Hajdu et al.)
- Coherent & magnetic scattering (DESY, BESSY, Uni HD, FH Remagen)
- Pump-probe experiment on CO$_2$ alignment (AMOLF Amsterdam)
- Femtosecond X-ray/optical cross-correlator (FU Berlin, Uni HH, DESY)
- Soft X-ray Autocorrelators (“Split & Delay Units”) (1. Uni Münster, BESSY & 2. Uni HH)
Streaking with FIR light

U. Frühling et al. (PhD thesis)

Figure omitted here
Coherent single-shot X-ray diffraction imaging

H. Chapman, J. Hajdu et al.
Image reconstructed from ultrafast diffraction pattern

SEM of structure milled into silicon nitride membrane

1st shot at full power

2nd shot at full power

Reconstructed Image – achieved diffraction limited resolution!
Wavelength = 32 nm

Figure 1 X-ray dynamic diffraction imaging. A visible-light laser beam (i) incident from the left is focused onto the sample (iii) and acts as the excitation pulse. A 10-fs duration soft X-ray pulse at a wavelength of 13.5 nm from the FEL (ii) is focused to a 20-μm spot in the same location as the visible-light laser at a continuously variable delay after the excitation pulse. The X-ray pulse diffracts from the sample, carrying information about the transient sample structure to the CCD detector (v) in the form of a coherent diffraction pattern. A 45° mirror (iv) is used to separate the direct beam from the diffracted light: the direct FEL beam (vi) passes straight through a hole in the mirror and is not detected in the CCD image. A 100-nm-thick zirconium filter over the CCD chip makes the detector blind to the laser excitation pulse. The sample (iii) consisted of a nanometre-resolution pattern etched into a silicon nitride membrane using a focused ion beam (FIB), providing a well-defined control sample so that the time evolution of a known structure could be observed. The path length from sample to CCD is 53 mm and the detected numerical aperture is 0.25, giving a spatial resolution of 27 nm in the sample plane.

True “high speed recording” of an explosion
A diffraction pattern and its real-space reconstruction, which was done at the beamline whilst collecting data. The sample is a pattern of Al cylinders, fabricated by e-beam lithography. The image was captured 20 ps after being hit by the FEL pulse (we used a multilayer mirror in the time-delay geometry to probe the sample with the same pulse that initiated the explosion). We will analyse the time series from identical structures to watch the evolution of the FEL-induced explosion.
Coherent scattering experiment

DESY, BESSY, Univ. Heidelberg, Rhein-Ahr-Campus Remagen

Sample: prepared by FIB

CXDI measurements at fundamental: 8 nm

Sample: double slit 5 µm separation

Exp. data and theor. Fit → 98% coherence

Experimental Diffraction Pattern

A.P. Mancuso et al., PRL 102, 035502 (2009)
Femtosecond X-ray/optical cross-correlator

FU Berlin, Uni HH, DESY

- use GaAs crystal
- change optical properties with FEL pulse
- probe with optical laser via changes in reflectivity

Autocorrelator / beam splitter (1)

Uni Münster (H. Zacharias), BESSY, DESY
Longitudinal coherence of FLASH pulses (1)

Coherence length at 8 nm: ~10 fs (~7 fs for 3rd harm.)
Pulse duration at 24 nm: ~30 fs

Uni Münster (H. Zacharias), BESSY, DESY

R. Mitzner et al., Optics Express 16, 19909 (2008)
Autocorrelator / beam splitter (2)

Uni Hamburg (A. Föhlisch, W. Wurth et al.)

- Delay Range: ± 6 ps
- Time resolution: < 1 fs
- Permanently installed in PG2
48 scientific publications since 2006

5 Phys. Rev. A,E
5 Appl. Phys. Lett.
1 Nature
1 Nature Physics
4 Nature Photonics
2 J. Phys. B
3 Optics Express

In addition, more than 16 submitted (6 to PRL)


6. P. Johnsson, W. Siu, A. Gijsbertsen, J. Verhoeven, A. S. Meijer, W. van der Zande, M. J. J. Vrakking, Velocity map imaging of atomic and molecular processes at the free electron laser in Hamburg (FLASH), J. Mod. Optics 55, 2693-2709 (2008); [http://dx.doi.org/10.1080/09500340802393062](http://dx.doi.org/10.1080/09500340802393062)


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