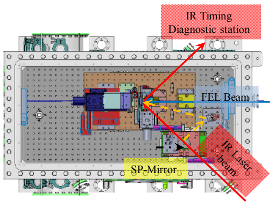
Elettra Sincrotrone Trieste

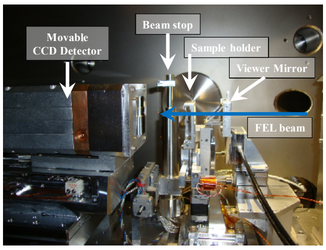
Coherent Diffraction Imaging to study ultrafast demagnetization

The multipurpose experimental station operated at the DiProI beamline of the FERMI@Elettra seeded FEL has welcome users since 2012. Thanks to its flexible design, the DiProI station takes full advantage of the state of the art performances of the ultrashort pulses of FERMI, namely high degree of temporal and spatial coherence, spectral purity and tunability, intensity and wavelength stability, linear and circular polarization. Jitter-free femtosecond time-resolution is achieved both with two-color FEL pulses generated in a twin-seed scheme and coupling the FEL with the IR seed pulses. All these features of the FERMI FEL have been exploited in several classes of experiments, ranging from integrated or single-shot coherent diffraction imaging to time resolved magnetic holography, from the excitation of exotic states of matter with two-color FEL pulses to the measurement of FEL-induced transient variation of IR reflectance and transmittance, FEL- optical laser wave mixing. The shorter wavelengths, down to 4 nm, made available for users by FERMI FEL2, allow to reach even better spatial resolution and to reach photon energies in resonance with core electron transitions. Further geometries of the chamber's setup will be implemented soon to perform more "exotic" experiments.

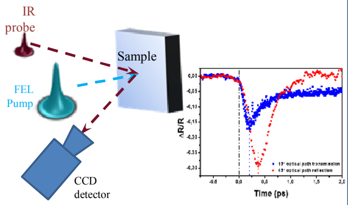
DiProI – end station

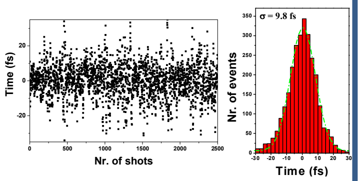
The DiProI end-station is designed to have modular versatility that allows for different schemes of scattering experiments both in static and dynamic mode. Several detectors can be allocated inside the vacuum vessel running from CCDs, i-TOF, bolometers or/and photodiodes. A particle injector can be installed into a dedicated flange to continuously deliver fresh sample into the FEL interaction region. The FEL beam is focused by an active optical system based on two bendable mirrors in Kirkpatrick-Baez (K-B) configuration positioned before the DiProI station. The K-B optical system is designed to focus the FEL beam to a spot size of approximately 5×6 μm² Full Width Half Maximum (FWHM) for FEL-1 and of 4×5 μm² FWHM for FEL-2 under the ideal condition of a pure Gaussian illumination.





To perform time resolved experiment a 80 fs optical pulse, directly derived by the same laser used to seed the electron bunch to generate FEL emission, is available to excite the sample. This scheme allows to reduce the arrival time jitter between the laser and FEL at the sample plane to less than 10 fs. For IR laser based pump and probe experiments, two optical laser paths have been conceived inside the vacuum vessel: the first one, impinging on the sample plane at an angle of 45°, and a second one, at an angle of 15°. The IR laser path inside the vacuum vessel can be switched without breaking the vacuum by inserting a movable mirror.

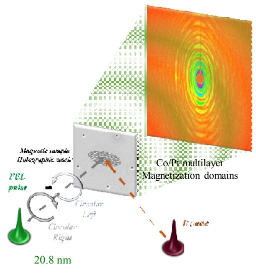


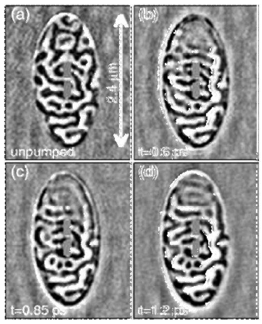


F. Capotondi et al., Rev. Sc. Instr. 84, 051301 (2013).
M. Danailov et al., Opt. Exp., 22, 12869-12879 (2014).

Time resolved resonant magnetic holography

When an ultrashort optical laser pulse excites a magnetic material it responds by an almost instantaneous reduction of its magnetization. Recent progress on all-optical control of ultrafast demagnetization and all-optical switching promises technological advances in magnetic data manipulation. The ultrashort, coherent and circular polarized X-ray pulses at the Cobalt M-edge (58.9 eV) met all requirements for implementation of X-ray magnetic circular dichroism (XMCD) based Fourier-Transform-Holography to image the ultrafast changes of a magnetic domain pattern. The reconstructed domain patterns for unpumped and optical pumped samples show a significantly reduced magnetic contrast between oppositely magnetized domains in the upper part of the elliptical object hole, indicating a pronounced demagnetization by the locally enhanced optical excitation.

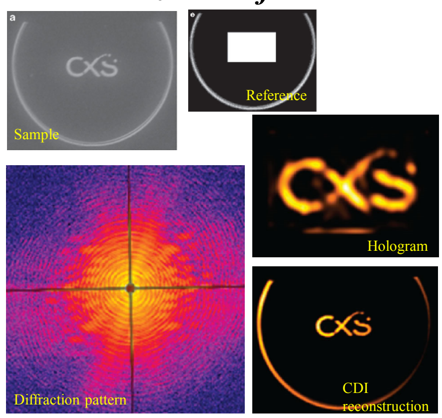




C. von Korff Schmising et al., Physical Review Letters 112, 217203 (2014)

X-ray holography with a customizable reference

Fourier-transform holography uses the interference between a known reference structure and the unknown object to directly and robustly recover a real-space image from a coherent diffraction pattern. However, when using a pinhole resolution can only be improved at the expense of flux, decreasing signal with respect to noise. To date, the choice of extended references has been limited to a few special cases where the analysis methods to recover the image are known. New Fourier-transform holography technique was demonstrated with an almost unrestricted choice for the reference. The flexibility is gained by using a conjugate-gradient algorithm to recover the image. Starting from the Fourier space experimental data, such an algorithm considers the autocorrelation function of the exit wave decoupled into its primary components, i.e. the autocorrelation of the scattering object, the autocorrelation of the holographic reference mask (known a priori) and their cross-correlation terms. These latter contain the holographic information for the reconstruction of the object in real space

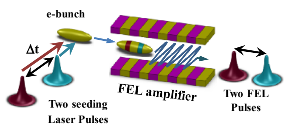


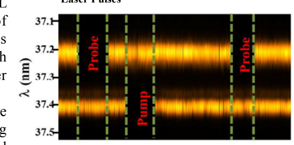
A.V. Martin et al., Nature Communications 5, 4661 (2014)

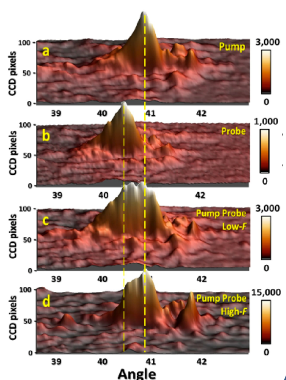
Two color FEL based pump-probe

Understanding the exotic properties of matter driven to extreme non-equilibrium states by interaction with very intense VUV/X rays needs the development of different photon correlation schemes, with temporal and spatial resolution determined only by the FEL pulse duration and wavelength. Taking advantage of FERMI seeding scheme, two independent FEL pulses can be generated seeding the same electron bunch with slightly different central seeding laser wavelengths.

The potential of twin-seeding pulse scheme to explore transient states of matter, stimulating and probing electronic transitions from core levels is demonstrated by a pilot pump-probe experiment with Ti grating structure deposited on a Si_3N_4 window. The selected wavelengths of both the pump (λ_1 = 37.2 nm) and probe (λ_2 = 37.4 nm) FEL pulses are within the slope region of the Ti $M_{2/3}$ resonance, where the Bragg peak intensities and positions are very sensitive to the instantaneous Ti ionization state. The results show that at low 'pump' and 'probe' intensities, the diffraction pattern is a simple sum of the 'pump' and 'probe' Bragg peaks. Using a very intense 'pump' pulse, the diffraction pattern undergoes an abrupt change due to dramatic loss of the 'probe' Bragg peak intensity. Since the sum of the delay time (~500 fs) and pulse duration (~100 fs) is shorter than those of hydrodynamic expansion and ablation, this result can be explained only by dramatic changes in the Ti electronic structure, namely highly ionized states of Ti atoms that pushes the $M_{2/3}$ resonance to shorter wavelengths.





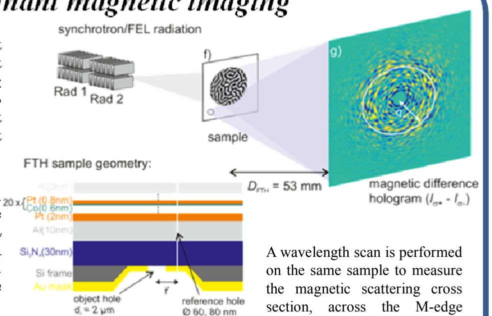


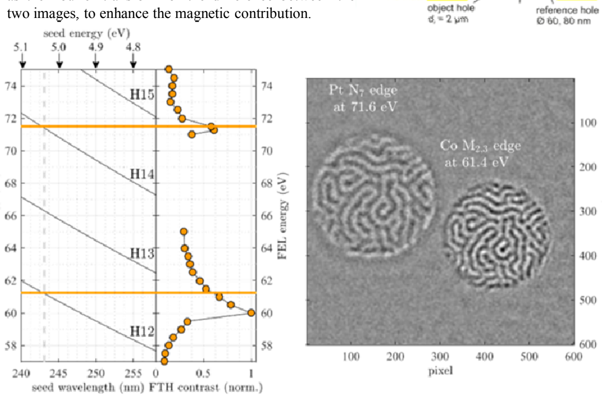
E. Allaria et al., Nature Communications 4, 2476 (2013)

Two-color resonant magnetic imaging

Nanoscale magnetic domain networks in Co/Pt heterostructure are spatially resolved through coherent imaging with Fourier-transform holography. Irradiating the holographic sample at the same time with two harmonics of the FEL seed, at resonance with O and Pt respectively, two element specific images are retrieved at the same time.

The Co/Pd magnetic specimen is covered by a gold holographic mask with 60 - 80 nm reference holes and a 2 μm wide circular sample area. Diffraction patterns are taken on a CCD when the sample is illuminated by FEL pulses with left and right circular polarization. A holographic image of the magnetic domains is retrieved as the Fourier transform of the difference between the two images, to enhance the magnetic contribution.





A wavelength scan is performed on the same sample to measure the magnetic scattering cross section, across the M-edge resonance of both Co and O. Tuning different sections of the FERMI@Elettra FEL to different harmonics of the same seed pulse, the sample can be simultaneously irradiated with two-color pulses close to both resonances and a double hologram can be retrieved, providing two different elemental sensitive images of the magnetic domains at the same time.

Multi-color, real-space spectroscopy at FEL sources can become a valuable tool to unravel ultrafast interactions within the electronic and spin structure of complex multicomponent and multiphase materials.

F. Willems et al., Structural Dynamics, 4, 014301 (2017)