ESRF	**Experiment title:** Towards a permanent installation for High Energy Density Science at ID-24	**Experiment number**: MI 1336
Beamline: ID 24	**Date of experiment**: from: 22.07.2018 to: 24.11.2018	**Date of report**: 25.04.2019
Shifts: 45	**Local contact(s)**: Nicolas Sevelin-Radiguet, Raffaella Torchio	*Received at ESRF:*

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Report:

We proposed the experiment MI1336 as a commissioning experiment to test the newly installed High-Power-Laser-Facility (HPLF) at ID24/ESRF, a unique combination of X-ray absorption spectroscopy (XAS) with synchrotron radiation and a high power optical laser system worldwide. The aim was to study phase transitions and material properties of Fe alloyed with Ni and Si shock compressed to high pressures and high temperatures, similar to conditions inside planets. Single-shot X-ray absorption spectroscopy is a powerful diagnostic for studying dynamics in high-energy-density matter since one can investigate the temporal evolution of both the ionic and the electronic structure of the compressed material. A complete characterization of high-energy-density matter is highly desirable to benchmark newly developed theoretical models in this field.
The experimental setup is shown in figure 1. The drive laser system during the commissioning phase provides 15 J in 9 ns pulses with a wavelength of 1.057 µm. We used a phase plate to create a 250 µm large spot, that results in a laser intensity of 3.5 TW/cm². The absorption in the components along the laser path is estimated to be 10% of the initial laser intensity. The generated ablation pressure drives a shock wave through the two-layer-sample: 60 µm thick plastic (parylene-N) followed by a 6 to 7 µm Fe alloy layer (provided by IMPMC and bougth from HMW Hauner GmbH & Co. KG). Via impedance matching, one can produce high pressure states of up to several 10th GPa in the Fe alloy sample with the available laser system. The energy dispersive setup (photon energy around 7.1 keV, pulse lengh of 100 ps, spot size of 15 x 100 µm) of beamline ID24 provides time-resolved single-shot X-ray absorption spectroscopy measurements of the created high-pressure, high-temperature material states. The time delay between the optical pump pulse and the X-ray probe pulse is easily adjustable while achieving a time resolution of 0.5 ns. Optical shock diagnostics, like SOP (streaked optical pyrometer) and VISAR (velocity interferometer for any reflector), give additional information about the shock characteristics.
The experiment consisted of 3 campaigns: the first campaign from 22nd to 28th july 2018 was used for bringing and installing streak cameras provided by HZDR to prepare SOP measurements. They can be also used in the

future in a VISAR diagnostic to get information about the shock wave. The second campaign was performed from 20th to 25th september 2018 during the 4-bunch-mode of the ESRF. This is the best suited synchrotron mode for this type of measurements, because it provides the highest possible number of photons per pulse and the largest seperation between the X-ray pulses. This ensures high-quality single-shot spectra and is best compatible with the X-ray XH detector. As a result of that campaign, we were able to prove the concept, but due to technical problems with the new laser and XH detector we could not collect a full set of data. As a compensation, a third experimental campaign from 19th to 24th november 2018 was offered to us. The 7/8+1 bunch mode of the synchrotron is challenging for the detector since the single bunch is very close in time to the high flux multibunch and the present version of the XH detector was not able to work at full performance, so that the signal-to-noise ratio was lower than expected. Despite this we successfully managed to take a series of X-ray absorption spectra for Fe3.5wt%Si for different time delays. In this campaign a point-VISAR provided by CEA was installed additionally to be able to extract pressures generated inside the compressed sample.
In figure 2 (bottom), data from the september campaign is presented, which demonstrates the high quality of single-shot absorption spectra achievable with this setup. A transition from the bcc structure of the Fe10wt%Ni at ambient conditions to the hcp structure of the shock compressed material is observed. First estimations show, that we could reach pressures of about 40 GPa and temperatures around 2000 K with this setup. In figure 2 (top) one can see data from a time-delay scan taken in november for Fe3.5wt%Si. On the right the data is shown smoothed because of the lower signal-to-noise ratio. However, we can see the structural evolution of the sample, which starts with a bcc structure at ambient conditions, that gets compressed until the bcc-to-hcp transition starts. We observe that this transition is not fully completed, because we always see a mixture of bcc (at lower energies after Fe K-edge) and hcp (at higher energies) signatures in the spectra. This is currently under investigation. Possible explanations are that we probe within the dynamics of the phase transition, that could be delayed in comparison to pure Fe, or that we see a combination of probed cold and shocked materials.
For the analysis of the obtained data it is crucial to know the exact values of the generated pressure and temperature inside the compressed sample. Since it is not possible to measure these quantities directly, several stategies will be applied to get a consistent understanding of the achieved conditions. We perform hydrodynamic simulations to calculate the thermodynamic conditions and will verify them by comparing the newly obtained shock compressed data on Fe alloys with several measurement campaigns on shock compressed pure Fe and static compressed Fe alloyed with Si and Ni. Additionally, VISAR measurements on Al foils will give us another constraint. Finally we will perform FEFF simulations for the estimated sample conditions. FEFF simulations with linear combinations of different amounts of bcc and hcp phases will be performed to study the origin of the mixture of phases during the bcc-to-hcp phase transition in Fe3.5wt%Si. A verification with model predictions from DFT-MD simulations is planned, too.
In conclusion MI1336 was a successful experiment. We could obtain high-quality single-shot XAS spectra from laser shock compressed FeNi and FeSi alloys, which will help to improve our understanding of material properties under extreme conditions. In the future the drive laser system will be upgraded to the final stage, so that higher pressures, similar to the Earth's core and higher, will be achievable. The option of pulse shaping and fully installed optical shock diagnostics, that can be used on shot, would be highly desirable. The HPLF at ESRF combines a bright X-ray synchrotron source with a high-power optical laser, that gives unique possibilities for creating and probing extreme material states in the laboratory. This is essential in the research of many fields like high energy density physics, warm dense matter physics, planetary physics, material physics and many more.

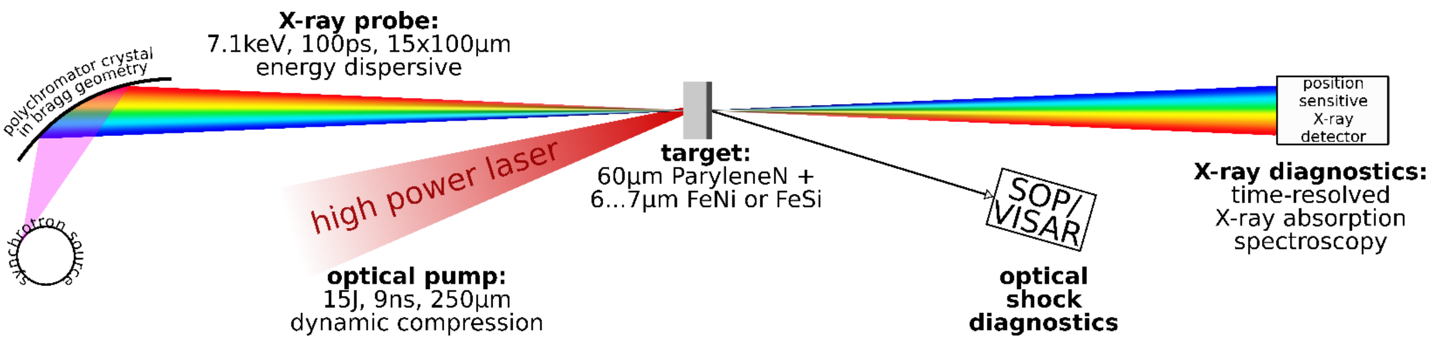
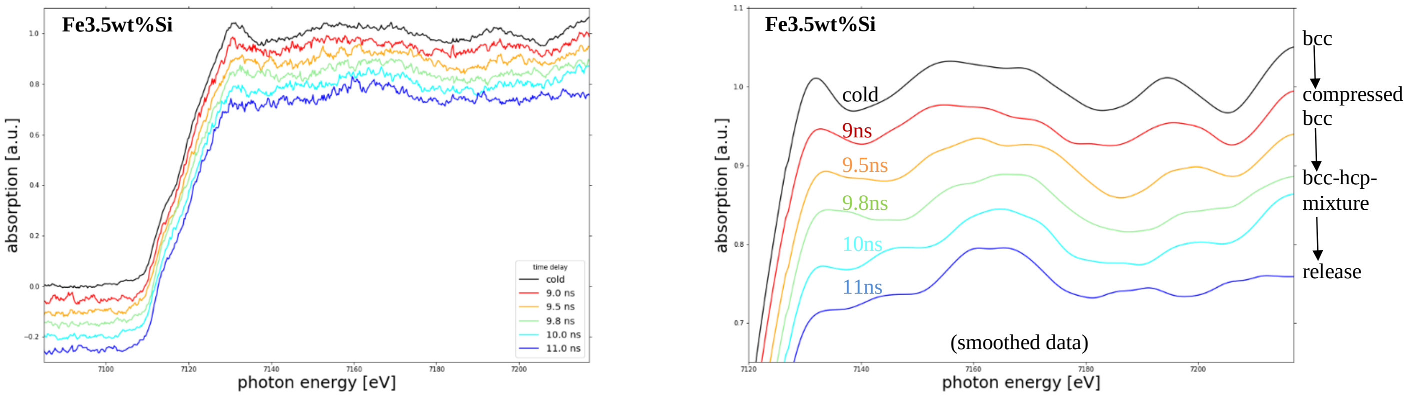


Figure 1: Setup sketch of experiment MI1336



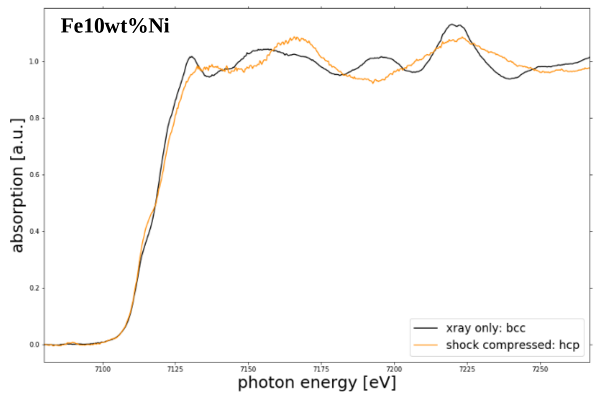


Figure 2: Normalized Single-shot X-ray absorption spectra of cold (black) and shock compressed (coloured) samples. Top: Scan of XAS spectra of Fe3.5wt%Si samples for several time-delays between the optical pump and the X-ray probe from the november campaign. On the right the same data is shown smoothed due to low signal-to-noise ratio during the 7/8+1 bunch mode of the synchrotron. Bottom: XAS spectra of Fe10wt%Ni samples from the september campaign during the 4-bunch mode of the synchrotron.