Local structure of laser shocked Fe-6.6%wtO probed by XAS

X-ray absorption Spectroscopy of Fe-6.6%wtO alloy under laser shock compression has been studied at ID24 in parallel with pure Fe samples. From the previous experiments performed at ID24 [Torchio et al. Scie. Report], we used the same geometry and target design (see figure 1).

The target is consisting on a multi-layer CH 4μm / Diamond 25μm / Fe-6.6%wtO 4.5μm / Diamond 25 or 50μm. The two diamond layers allow maintaining high-pressure for several ns (see figure 1), which is required for probing with the 100ps synchrotron bunch. As seen in the hydrodynamic simulation, the provided laser intensity allowed to reach pressures above 300GPa, ie above the melting curve of Fe and Fe-O alloys.

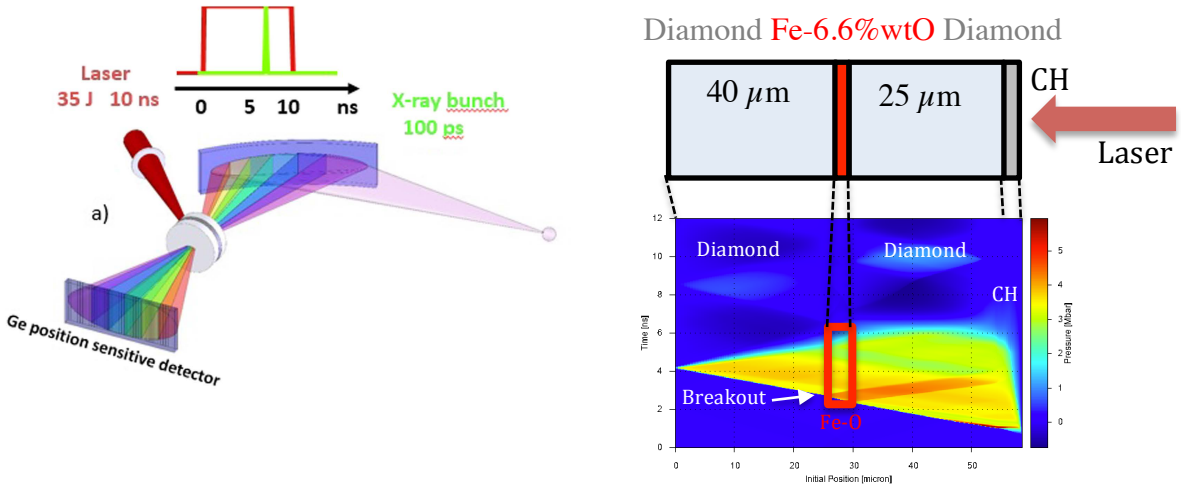

Figure 1 : Experimental set-up from Torchio et al. [1] and equivalent target design used during our experiment HC 2588. Hydrodynamic simulations (Multi) of the laser shock compression (Pressure along the sample and in function of time) for a 2. 10^{13} W/cm² (5ns square pulse, 130µm focus, 20J) and using an ad-hoc equation of state for Fe-6.6%wtO alloy. The so-called Fe-O breakout time is indicated and corresponds to the moment when the shock wave quits the Fe-O layer and enters the rear-side diamond.

Because the laser shock compression is intrinsically transient, it is necessary to perform delay scan between the laser pump and the X-ray probe and to catch the breakout time of the shock wave at the interface of Fe-O and the rear side diamond. Figure 2 – left shows X-ray absorption spectra obtained for Fe-6.6%wtO at similar laser intensities and for various delays between the pump and the probe. The indicated time delays, varying between 6 and 12ns are not absolute values. We notice that Fe-O samples show a series of phase transitions in function of the delay, first a bcc – hcp and finally an hcp – melt transition for later times. The sample remains in an hcp phase during several ns and intermediate mixtures are also observed. The melt appears at later timing, ie. 12ns. These observations would suggest that the melt is obtained during the ultrafast release of the wave and not along the Hugoniot itself. Indeed, hydrodynamic simulation (figure 1 – Right) shows that the diamond sandwich allows to maintain the pressure for ~3ns which is corresponding to the time during the hcp phase is maintained (figure 2-Left).

Figure 2 – right shows quantitative comparison with statically compressed Fe-5%wtO sample (LH-DAC at ID24-ERSF, G. Morard et al.). Even if the pressure and temperature ranges are not the same, this qualitative comparison allows gaining confidence in the melting signature during shock compression. Both static and dynamic compression of similar Fe-O alloys show the smoothing of the edge and of the EXAFS features. However, we observe differences on the first oscillations: the first XANES oscillation is more visible at late timing while the second oscillation quickly vanishes. At this point we want to stress significant differences

between static and dynamic compression that prevent any further analysis from this comparison:

- The temperature and pressure ranges are significantly different: 60GPa – 2800K for LH-DAC and 350GPa – ~8000K with dynamic compression.
- While LH-DAC samples can be easily contaminated during the data acquisition, the laser shock time scales (ns) do not allow any significant diffusion during the compression process (only for nm layers at worst). In general it allows obtaining high-quality X-ray absorption spectra [1]. The quality of the XANES spectra can be limited if important gradient exists in the sample. This is related with the fluctuations of the sample quality or the laser spatial profile. In our case, this might explain some non-systematic features in our data.
- The ultrafast thermodynamic pathway of laser shock compression, i.e. shock Hugoniot followed by a quick release has a strong impact on the observed data as it involves ultrafast changes of the pressure and temperature conditions during the shock process.

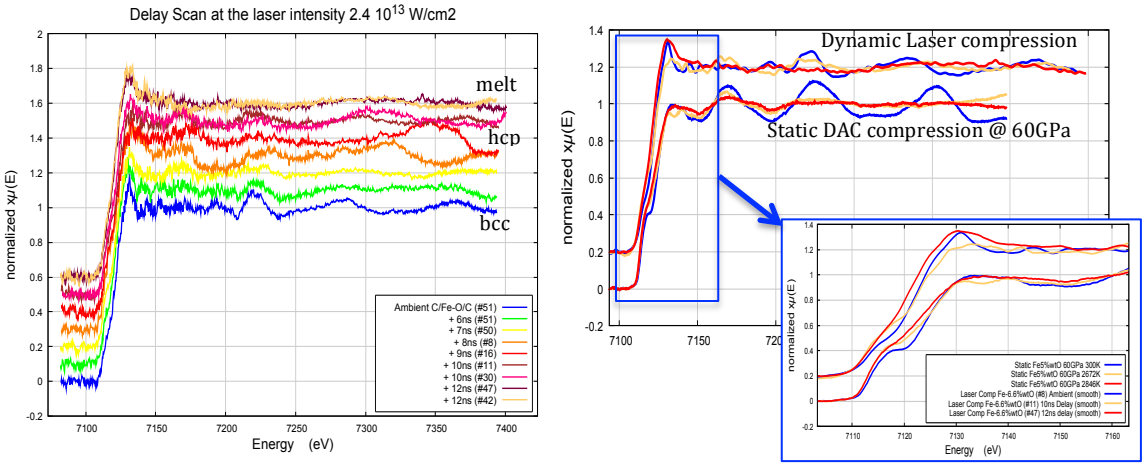

Figure 2 : Left – X-ray absorption spectra for various delay between the laser pump and the X-ray probe to indicate the dynamic of the shock within the Fe-O layer. Right – Comparison with LH-DAC data on Fe-5%wtO at 60GPa (Morard et al.). The onset is a zoom of the absortpion edge showng the melting criteria for such Fe alloy.

During the experiment, parallel measurements were also performed on pure Fe at the same laser shock conditions. Figure 3 shows a comparison of Fe-6.6%wtO and pure Fe X-ray absorption spectra for similar laser intensity conditions (2.4 10^{13} W/cm^2) and the corresponding studied pressure and temperature conditions along the shock Hugoniot and release. We can observe that the hcp and liquid features are different for Fe and Fe-6.6%wtO, especially around the edge, in the XANES part of the absorption spectra. Further advanced analysis is required to extract information from the measured spectra, especially in comparing this XANES feature with the well-known FeO XANES spectra and extracting Fe-6.5%wtO liquid densities if possible.

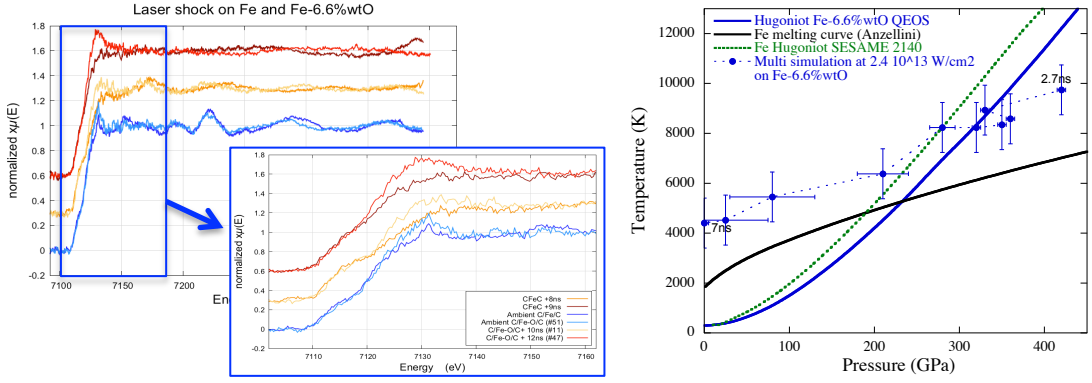

Figure 3 : Left – Absorption spectra for Fe and Fe-6.6%wtO at the same laser conditions. Right – Hugoniot path of Fe and Fe-6.6%wtO and expected conditions in the target from Multi simulations at 2.4 10^{13} W/cm² over several ns.