Platform for combined heavy-ion high-energy-laser experiments

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Understanding the behaviour of warm dense matter (WDM), i.e. matter at temperatures of 1-10 eV and at pressures of 1-100 Mbar, is essential for planet modelling, as such conditions prevail in the interiors of many astrophysical objects. Such states of matter can be created in the laboratory using powerful drivers, albeit, their behaviour can be influenced by the kind of driver used to generate them. In contrast to shock-driven WDM, generated by high-energy nanosecond lasers, at GSI, Darmstadt, heavy ions represent an alternative type of powerful driver with the prospect of allowing for large volumes of WDM to be generated in uniform physical conditions in local thermal equilibrium on relatively long time scales [1]. Following previous studies at the HHT exper-imental cave at GSI [2], we have recently equipped this experiment station with a beamline for the high-energy nanosecond laser pulse of PHELIX, allowing for laser-driven X-ray diagnostics on matter heated by the heavy-ion beam.

Laser-driven X-ray diagnostic methods are particularly suited for studying heavy-ion heated WDM, as they provide bulk information on changes in the structure of the sample (e.g. X-ray diffraction) and/or information on the temperature (e.g. X-ray Thomson Scattering or X-ray absorption spectroscopy). Fig. 1 shows the experimental setup in the HHT target chamber of our recent commissioning experiment. A suite of diagnostics were used for the investigation of heavy-ion heated states of matter. The ion number and temporal shape of the ion pulse were recorded by using a fast current transformer (not shown in picture). The spatial size at the best focussing condition was determined by using beam-induced fluorescence in Ar gas (BIF) and optical transition radiation in an Al foil (not shown here). Two different pyrometry setups were used for temperature measurement, a multi-channels setup to give precise temperature information from one point on the target, the other provides spatial resolution by imaging the thermal emission in two spectral channels. PHELIX provided 2-ns-long pulses with 200 J of energy at 527 nm, focussed with an F/13 lens for the X-ray generation. These pulses impinging on Ti and Cr backlighter foils resulted in He-α line emission at 4.75 keV and 5.68 keV, respectively. In an elaborate target assembly the X-rays then propagated to the target that was heated by the heavy ion beam, where they were scattered and diffracted. The generated X-ray spectrum (X-spec), the X-ray Thomson scattering (XRTS), and X-ray diffraction (XRD) signals were recorded.

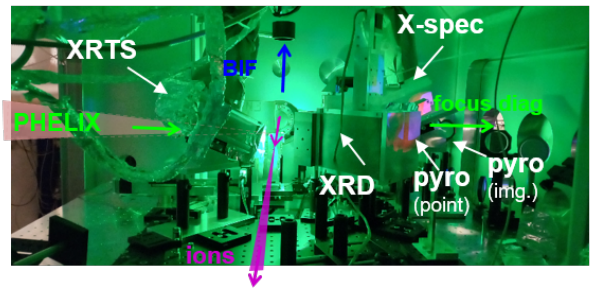
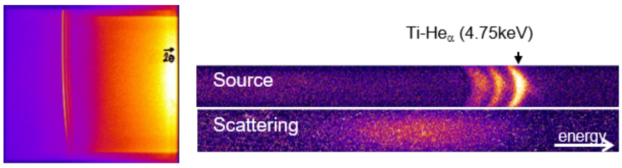


Figure 1: Experimental setup in the HHT target chamber.

In this first experiment using both the heavy-ion beam and the PHELIX laser pulses, we investigated the effect of heavy-ion heating on diamond and iron. While the detailed analysis is still ongoing, Fig. 2 shows XRD and XRTS data demonstrating that we are clearly able to resolve diffraction/scattering signals above the background mainly caused by the heavy-ion beam itself, thereby demonstrating the capability to obtain structural and temperature information. In conclusion, our diagnostic suite at HHT now includes laser-driven X-ray capabilities that have been successfully applied in a first proof-of-principle combined heavy-ion, high-energy laser experiment. While the methods themselves were proven to work, the limitation in available heavy-ion intensity has sofar prevented us from entering the interesting WDM regime. This limitation is expected to be overcome by the upcoming FAIR facility, where we will apply the diagnostic methods that we have developed during the ongoing FAIR phase-0 programme.



a) XRD b) XRTS

Figure 2: Preliminary X-ray diffraction and X-ray Thomson scattering images using Ti as backlighter and diamond as the target.

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References

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