X-ray Thomson scattering to measure temperature and charge state of short-pulse laser-heated matter*

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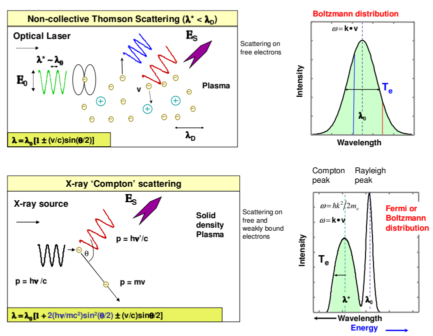
We have developed x-ray Thomson scattering as a method to accurately measure plasma properties of short-pulse laser-heated matter [1,2]. We apply the 8.6 keV Zn Kα line source as an x-ray probe on the unique kJ-class dual short-pulse laser facility OmegaEP. In this talk we present x-ray scattering spectra from short-pulse heated Be. The spectra show elastic and inelastic scattering features. The goal of this experiment is to infer the plasma temperature from the width of the Compton peak, and the charge state from the ratio of the inelastic to the elastic scattering feature with high temporal resolution.

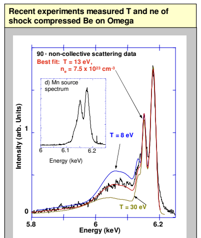
Referencer:es: [1] S.H. Glenzer, and R. Redmer, Rev. Mod. Phys., in print (2009); [2] A.L. Kritcher et al., Science 322, 69 (2008).

From optical to x-ray Thomson scattering



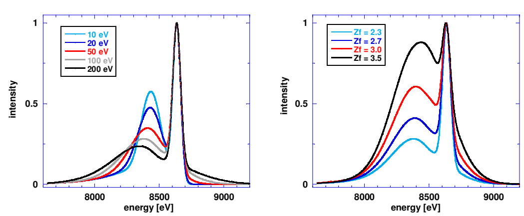
- Non collective x-ray Thomson scattering is proven to yield accurate plasma temperature
- X-ray Thomson scattering with a K-α x-ray probe has been demonstrated on the Titan laser (Kritcher et al., [2])
- K-α backlighter allow for high time resolution
- A new high throughput spectrometer was developed to cope with high noise environment on OmegaEP
- Diagnostic platform is readily applicable to a variety HED experiments on OmegaEP (e.g. ElecXport-EP-09)
- future application to collective regime will provide conductivity measurement through broadening of plasmons
- **For the conductivity measurements we request to implement a 100 – 200 ps pulse width capability for the 3w OmegaEP long pulse beams**

Recent experiments measured T and ne of shock compressed Be on Omega



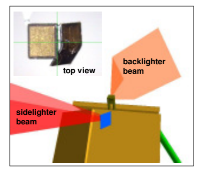
HJ Lee et al., PRL 102, 115001 (2009).

T_e and Z_f will be inferred from the XRTS spectra

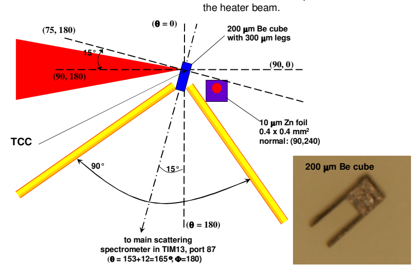


Synthetic scattering spectra, assuming a Zn K-α line source at 8.64 keV with a source function of 50 eV FWHM and a scattering angle of 110°, show the sensitivity to the electron temperature (left) and the charge state (right), where a constant charge state Zf = 2.3 and a constant temperature Te = 100 eV was considered, respectively. The shift of the inelastically scattered signal for temperatures above 50 eV is due to stronger bound-free contributions.

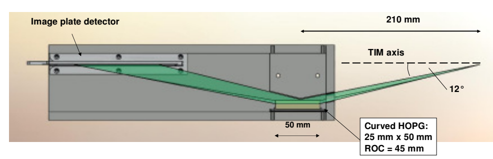
Experimental configuration



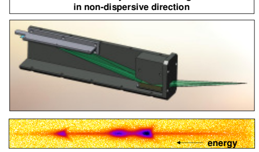
The OmegaEP backlighter beam isochorically heats a 200 μm Be cube through collisions with refluxing electrons. The delayed OmegaEP sidelighter beam creates the Zn K-α x-ray probe at 8.64 keV which is scattered off the Be plasma in backscatter geometry (110°) towards a high throughput crystal spectrometer in von Hamos geometry, operated in TIM13. Due to the short-lived x-ray probe plasma temperatures inferred from the scattering spectra are measured with high temporal resolution of order 10 ps. The short-pulse beam delay is monitored by an ultrafast x-ray streak camera. Gold shields block the direct line of sight of the spectrometer towards the Zn foil and the Be plasma emission caused by the heater beam.

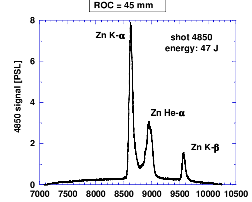


A dedicated high throughput spectrometer in von Hamos geometry was fielded



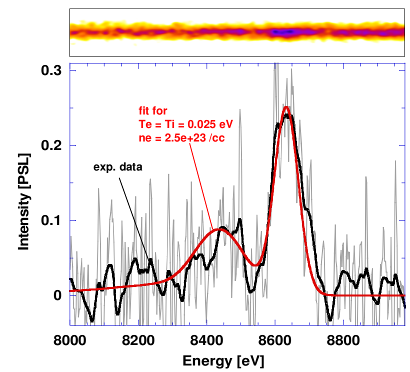
The curved crystal focuses signal in non-dispersive direction





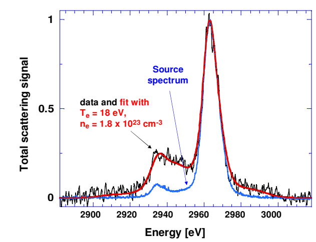
The Zink von Hamos (ZVH) spectrometer utilizes the strong integral reflectivity of highly oriented pyrolytic graphite (HOPG) which is curved in the non-dispersive direction to focus the spectrum at the detector plane. Besides a high sensitivity this also allows to discriminate between continuum background radiation created at the target and unfocused background origination from the chamber walls or the spectrometer housing.

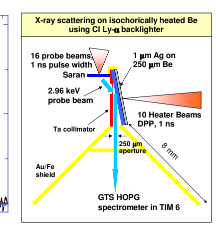
A full scattering signal was recorded with only 180 J to create the x-ray probe



The plot shows a full scattering spectrum for a cold Be case. The sidelighter beam delivered 180 J to the Zn foil to create the 8.6 keV K-α x-ray probe. The strength of the scattering signal is in good agreement to the estimated signal level. The high noise level is due to the strong background which will be significantly reduced by modifications to the spectrometer housing. The scattering data are in very good agreement to the synthetic scattering spectrum expected for cold Be.

In the future we will use the unique short-pulse laser capability of OmegaEP to isochorically heat Be and measure conductivity from plasmon broadening





On the Omega laser we used Ag L-shell x-rays to isochorically heat beryllium. 10 heater beams with a total of 4.8 kJ at 3w were necessary to reach an electron temperature of 18 eV. The short-pulse capaplity of OmegaEP will allow to heat comparable samples to significantly higher temperatures through isochorically heating either with fast electrons or protons within a shorter time, thus maintaining solid density.

In the collective scattering regime, which in general requires a lower probe energy and a smaller scattering angle, we measure the response from plasmon oscillations. The ratio of the up-shifted to the down-shifted plasmon is determined by detailed balance and allows to infer Te from first principles. The plasmon shift is a function of both density and temperature.
In the shown example we used a Cl Ly-α source at 2.96 keV to probe the plasma properties. A temperature of 18 eV and a density of 1.8e+23 /cc is extracted from the scattering data.

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