Optimization of a laser-plasma-based X-ray source according to warm dense matter absorption spectroscopy requirements

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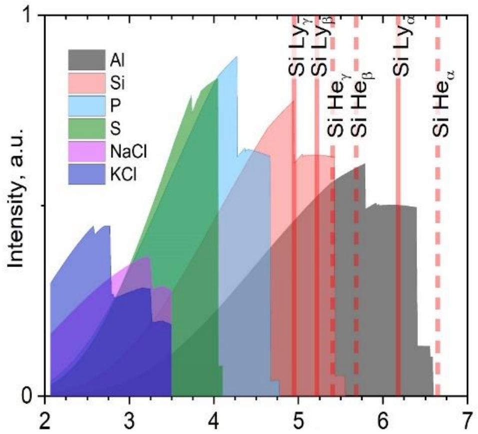
1. In short

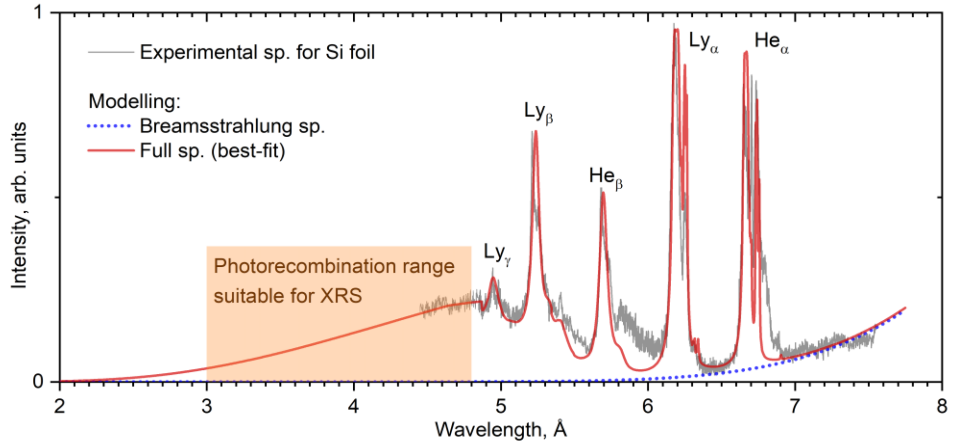
X-ray absorption spectroscopy is a well-accepted diagnostic for warm dense matter experimental studies. It requires a short-lived X-ray source (XRS) of sufficiently high emissivity and without characteristic lines in a spectral range of interest. In our recent work [1], we discuss choosing its optimum material and thickness to get a bright source in the wavelength range of 2-6 Å (~2-6 keV) considering relatively low-*Z* elements. We demonstrate that the highest emissivity of solid aluminium and silicon foil targets irradiated with a 1 ps high-contrast sub-kJ laser pulse is achieved when the target thickness is close to 10 μm. An outer plastic layer can increase the emissivity even further.

2. Modelling



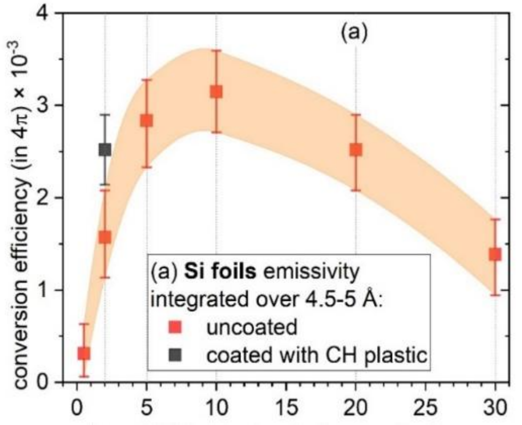
We performed an optimization of a laser-plasma-based XRS for absorption spectroscopy by considering the merits of different materials and targets of different thickness. Here n_i = solid density and $\boldsymbol{n_e T_e} + \sum \boldsymbol{N_k I_k} = \boldsymbol{const}$.

It illustrates that the photorecombination continuum peak intensity is roughly equal for each element and can be used to choose the appropriate XRSs for various wavelength ranges. For example, aluminium is best for 5-5.7 Å range, silicon appears to be the appropriate option across the spectral range of 4.25 5 Å, whilst phosphorus is suitable for 3.75-4.25 Å range.



3. Photorecombination emission range

Plasma X-ray source (XRS) spectra may contain characteristic lines as well as continuum emission of free-free (bremsstrahlung) or bound-free (photorecombination) transitions. A continuum XRS, i.e. one dominated by bremsstrahlung or recombination emission without spectral lines, is superior for XAS. Figure shows a comparison of experimental data (grey curve) with a model spectrum (red curve). Modelled spectrum is a sum of photorecombination, characteristic, and bremsstrahlung spectra – the last one is indicated with a dotted blue curve. The orange polygon indicates a wavelength range that is best suited for X-ray source based on Si (3-4.8 Å).



4. Conversion efficiency vs thickness

Dependences of experimentally measured conversion efficiencies of deposited laser energy to the energy of emitted photons on the thickness of solid silicon foil targets. The data clearly reveals an optimal target thickness of around 10 μm. The advantage of using plastic coated targets to bury the emission layer is highlighted by the black square data point in the figure.

4. Conclusion

low-Z materials such as aluminium and silicon can be used as X-ray backlighting in a hard X-ray range 2-6 Å (2-6 keV). Emphasis was placed on the photorecombination continuum emission of solid-density plasma to create a featureless spectral continuum of high intensity for use in for example x-ray absorption spectroscopy studies of warm dense matter. It is essential to use a high-contrast, high-intensity, short-duration laser to create these X-ray sources and that an optimal target thickness of close to 10 μm is necessary.

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