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Periodic features modifying the Heβ line profile from an aluminium plasma

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INTRODUCTION

Laboratory experiments involving the irradiation of solid targets using short pulse, high intensity lasers allow the generation and study of transient, solid-state-density, small-scale length plasmas. These experiments offer the opportunity to study time-dependent atomic kinetics effects since the pulse duration is comparable to the atomic processes time scale. X-ray spectroscopy is an extremely valuable tool to infer the properties of these high-density states[1]. In this work we report the observation and analysis of X-ray emission produced by picosecond laser irradiation of a solid Al target. The use of a high-luminosity, high-resolution spectrometer has enabled the measurement of unusual intensity modulations on Heβ transitions**.** The hydrodynamic and thermodynamic behavior of the expanding plasma is calculated using one-dimensional hydrodynamic simulations.

EXPERIMENT

In the experiment 200 μm diameter 8 cm long aluminium fibre targets were irradiated using the Gaussian laser pulses produced by the RAL Astra facility (wavelength 800 nm, FWHM pulse duration 3.4 ps). An off axis parabolic mirror OAP was used to focus the laser pulse onto the target with an angle of 10° to the vertical axis. By defocusing the OAP, the on target focal spot varied to give intensities between 7×10^{14} W cm^{-2} and 3×10^{16} W cm^{-2}. By translating the aluminium fibre through the focal spot and firing the laser at a repetition rate of 2 Hz, up to 100 shots were integrated to make a single recording. The high-resolution, highly dispersive toroidally bent crystal spectrometer (HDTS)[2] was positioned to record spectral emission parallel to the target surface and spatially resolved perpendicular to the surface. The spectral measurements were recorded with 3 μm spatial resolution having a magnification of the crystal of about 4. The energy dispersed X-ray emission from the plasma was recorded onto a cooled, large area scientific-grade CCD camera. The experimental setup is shown from above in Fig 1a. Typical data integration times were approximately 1 minute. The spectrometer was positioned to disperse an energy range of 1830 eV to 1872 eV containing the

Al^{+11} He β (1s3p $^1P_1 \rightarrow 1s^2\ ^1S_0$) transition and neighbouring Li-like dielectronic satellites. The distance between target-crystal and crystal-CCD was 245.6 mm and 1095.1 mm respectively. This gave a spectral spatial resolutions of ~ 0.2 eV. A magnet and lead shielding was used to prevent hot electrons striking the CCD and to limit hard X-ray bremsstrahlung background.

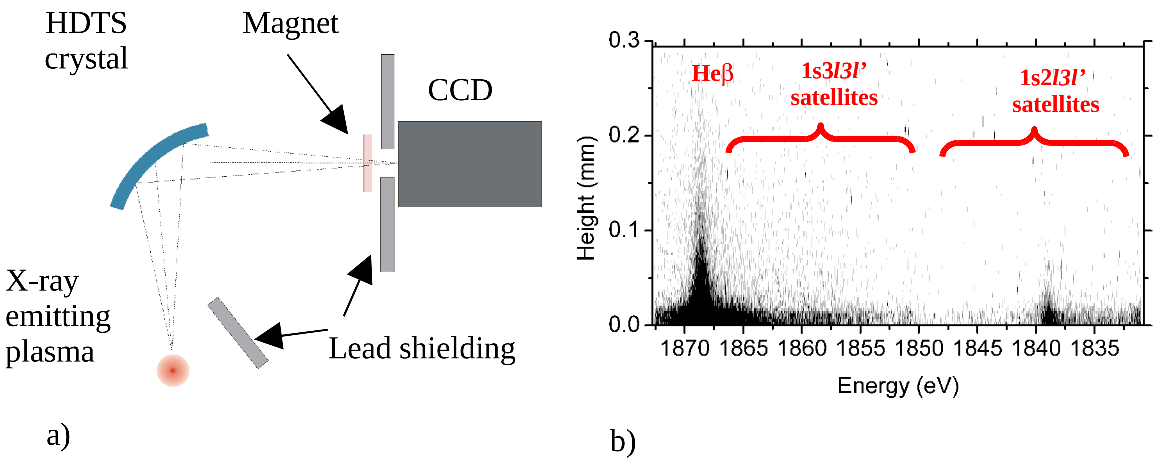


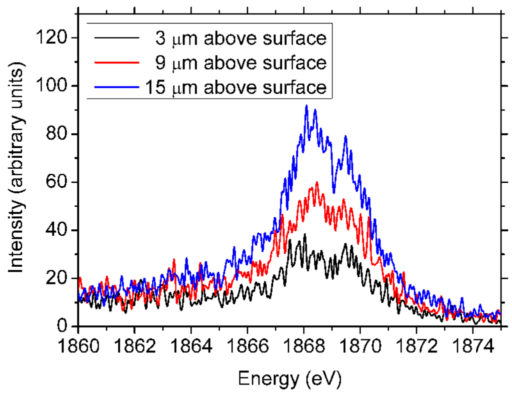
Figure 1. a) Experimental geometry and b) a sample of spatially resolved time integrated data.

RESULTS AND DISCUSSION

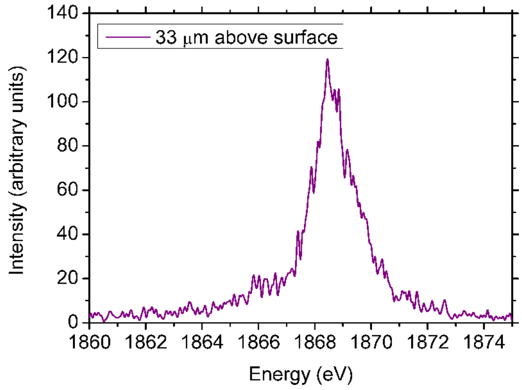
Fig 1b shows a sample of time integrated spectral data. The photon energy is shown along the horizontal axis, whereas the distance above the irradiated target surface is shown along the vertical axis. Hot electrons generated during laser-target interaction directly striking the CCD are primarily responsible for the random speckle. The raw data illustrates the need to integrate over a number of shots; this was required to improve the signal to noise ratio particularly as the spectra are highly dispersed (0.8 mm/eV). Spectral information is detected between the target and to 0.2 mm above the target surface. Close to the initial target surface the Heβ resonance lines and Li-like dielectronic satellites are clearly resolved. These satellites are strongly correlated to an excited 1*s3p2l* states populated by collisional processes at high plasma densities[3].

Spectral traces extracted from data such as Fig 1b were averaged over 6 μm in plasma height. This is repeated at a number of positions above the target surface. An example is shown in Fig 2. Here spectral line profiles of the Al Heβ transition taken at 3, 9, and 15 μm above the target surface in Fig 2a and at 33 μm above the target surface in Fig 2b. The curves show line profiles typical of 3.4 ps duration pulse at 3×10^{16} W cm^{-2}. The Heβ resonance line (1*s*3*p* $^1P_0 \rightarrow 1s^2\ ^1S_0$) at 1868.7 eV is clearly seen. A dip in the line shape observed close to

1869.2 eV is interpreted as a distinct absorption feature. High electron densities during the period of the spectral line peak emission result in the broad profile observed close to target surface.



a)



b)

Figure 2. Cross-sections of the Al Heβ profile are shown a) close and b) far from the target surface.

Of particular interest are the regular intensity modulations on the Heβ line profile, as shown in Fig 2. These modulations are particularly intense close to the target surface, and observed to extend above the target surface. At greater heights above the target surface the modulations reduce in amplitude in comparison to the integrated resonance line emission and the spacing between neighbouring modulations increases, as illustrated in Fig 3. Measurements show that these modulations always occur at different laser intensities (from 7 $\times 10^{14}$ to 3×10^{16} W cm^{-2}) and are well reproducible.

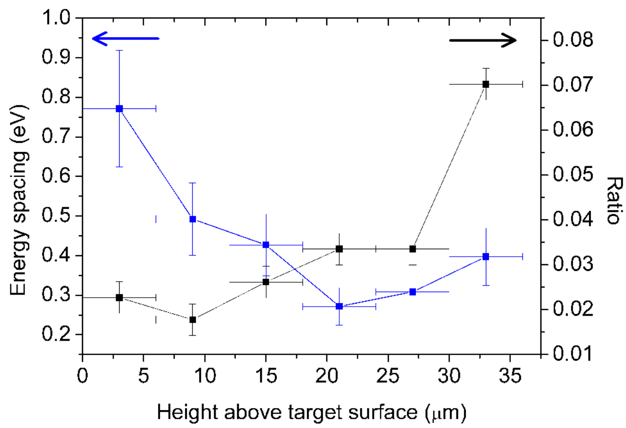


Figure 3. Ratio between modulation amplitude and integrated resonance line emission, and spacing between modulations versus height above the target surface.

As the spectral measurements are spatially resolved but time integrated we have used the 1-dimensional Lagrangian hydrocode MED103[4] in conjunction with the atomic physics code FLY[5] to infer the spatially resolved electron temperature and density at peak He β emission. It is assumed the modulations observed in the spectral data occur at the time of peak He β emission. If this comparison is valid the simulations suggest the modulations are present in regions where the electron density exceeds the critical density (1.7×10^{21} cm^{-3}) and *during* the time of laser-plasma interaction. This suggests that modulation intensity may be dependent on the absorption of the laser energy at different plasma densities. The simulations show that the period of peak He β emission at heights above 20 μm from the target spans from 46 ps to 54 ps related to the laser pulse maximum; the slightly variable plasma parameters corresponding to this emission period may smear the modulation contrast.

CONCLUSIONS

High-resolution aluminium K-shell spectral data have been obtained from picosecond laser pulse experiments. Regular intensity modulations on the He β line profile are observed at spatial positions close to the target surface. Hydrodynamic simulations suggest that these features occur during the laser-plasma interaction and at electron densities that exceed the critical density. The origin of these modulations and the dependence on laser and plasma conditions are currently being studied.

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