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Efficient K-α and He-α emission from Ti foils irradiated with 400 nm, 45 fs laser pulses

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Abstract

We have used the ASTRA laser facility to irradiate Ti foils with 45-fs 400 nm laser pulses at irradiances up to $\sim 10^{19}\,\mathrm{Wcm^{-2}}$. We have observed both thermal line radiation, in the form of the He-like $1s^2$-1s2p transitions (He-α), and the K-α emission line. We have noted that the efficiency of K-α production is in excess of 2×10^{-4} and thus compares well with using the fundamental 800 nm radiation. The behaviour of the K-α emission as a function of polarisation and angle of incidence suggests a vacuum heating mechanism as the principal source of the fast electrons necessary to create the inner-shell vacancies. Use of streak cameras in the X-ray regime has demonstrated that the emission of both K-α and He-α radiation lasts several picoseconds. In the former case, this would seem to imply that fast electrons generated by resonance absorption are circulated for some time before penetrating the foil.

Keywords: X-ray; Spectroscopy; Laser-plasmas

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1. Introduction

The study of K-α emission from ultra-short pulse laser produced plasmas has been pursued by several groups (see e.g. [1–13]). The study of such emission can give clues to the propagation dynamics of electrons in different types of solid and as such is important in the development of schemes such as fast ignitor fusion and fast X-ray sources. Furthermore, if suitable short pulse X-ray beams can be generated then these may be used in a variety of experimental techniques, such as ultra-fast diffraction [14] from dynamically compressed solids or X-ray scattering from non-equilibrium dense plasmas [15].

Using fundamental laser radiation, usually at 800 nm, experiments on a variety of target materials with pulses from 30–200 fs [1–13] have shown typical K-α conversion efficiencies in the range $10^{-6}-10^{-4}$. Our own previous work on ASTRA [9] showed peak conversion to K-α of $\sim 10^{-4}$ for 800 nm wavelength. However, preliminary experiments with second harmonic light [16] showed exceptional conversion efficiency of nearly 6×10^{-4}. The pulses used were converted from the p-polarised 800 nm beam by a type I KDP crystal, generating 30 mJ, s-polarised pulses of $\sim$45 fs duration.

In the preliminary experiment only s-polarised data was taken and a fuller experiment was carried out as described below. The reason for taking time to mention the preliminary data is that the high yield for s-polarisation was not reproduced in the full experiment described below. The data was collected in the same way with the same spectrometer and same focussing parabola. However, there was a crucial difference in that the preliminary experiment was carried out prior to a vacuum spatial filter (VSF) being fitted to the laser and thus the focal spot quality was better in the later work. It is possible that the preliminary data had more "hot spots" in the beam and as we see below in the analysis this may be a salient point.

2. Experimental set-up

Fig. 1 shows the layout for the experiment. The KDP type I crystal was 0.6 mm in thickness and converted up to 20% of the incident laser light to 400 nm. The laser produced up to 500 mJ at 800 nm in 40 ± 5 fs and tests with a calorimeter showed typically 60 mJ of 400 nm light on target per shot. The 400 nm beam was reflected off 3 dielectric mirrors thus rejecting the unconverted ASE pre-lase and pre-pulses effectively. After reflection from a Ag mirror, the beam was focussed onto target by a Ag coated off-axis parabola (OAP) in an f/2.5 cone.

For alignment of the target an expanded green diode laser was injected through the back of the third dielectric mirror, see Fig. 1. This was set to be collinear with the main 400 nm beam. Because we use reflecting optics the focal spot was at the same position and in the same plane for both beams. Using a microscope objective to image the focal plane we were able to ensure that this was the case. A 10 μm wire was then inserted into the focal plane and the reflection of the focal spot from this was transmitted back to the alignment system and an image of the focal spot formed on a CCD camera equipped with an objective. In this way, when the target foil was moved 1mm between shots, the position of best focus onto the foil could be identified using the very small amount of backscattered light even from smooth target surfaces. This allowed the use of angled targets and corrected for any drift in the target plane as the target moved. Leakage of 400 nm light