Effects of Prepulse and Incidence Angle on High-Energy K-alpha Production

J. Kuba[1], M. Foord[1], N. Izumi[1], M. H. Key[1], J. A. Koch[1], S. Moon[1], H. –S. Park[1], T Phillips[1], B. A. Remington[1], R. A. Snavely[1] and S. C. Wilks[1], B. Zhang[2], K. Akli[2], J. King[2], W. Theobald[3], C. Stoeckl[3], R. Heathcote[4] and D. Neely[4]

[1]The University of California, Lawrence Livermore National Laboratory, Ca, USA
[2]The University of California at Davis, Ca, USA
[3]LLE, The University of Rochester, NY, USA
[4]Rutherford Appleton Laboratory, Chilton, Didcot, United Kingdom

Introduction

We report on development of high-energy (20-100 keV) K-alpha sources for back-lighting applications at the National Ignition Facility. The sources are produced by high-power short-pulse (0.1-10 ps) lasers upon interaction with a solid target. The laser energy couples efficiently in to hot, relativistic electrons. The electrons drive the high-energy x-rays production. The K-alpha production thus depends on the laser beam parameters in a relatively complex way. Preliminary experimental [1] and theoretical [2] studies have been carried out for some irradiation parameters. In the present study we concentrate on the role of prepulse and laser incidence angle in the interaction of a 10^{19} W/cm^2, 500-fs laser pulse with a solid target.

Experimental Setup

The experiment was carried out at the VULCAN 100-TW Nd:Glass laser facility at the Rutherford Appleton Laboratory (United Kingdom). The laser provided two beams at the fundamental wavelength λ_0 = 1054 nm: The first, a short CPA (heating) pulse of up to 100 J on target in 10 ps and a second, long (prepulse) beam with the maximum energy of 100 J in 600 ps. The heater beam was focused by an off-axis parabola to a 10-µm diameter spot, while the long pulse was focused to a 1-mm diameter spot. The "normal" incidence angle in this configuration was 15.5º±0.8º for the heater beam and –5º for the long pulse. Both beams were timed to set up the peak-to-peak delay of (800 ± 50) ps between the long and the short pulse. The targets were 50x500x500-µm silver squares mounted on a 30-µm-thick optical fibre. The output x-rays were measured by a set of two single-hit CCD cameras that were properly filtered by optimizing the distance between the target and the CCD, and filtering by 150-µm thick Ag filters in one case and a combination of 50-µm thick Ag filter, 3-mm Lucite window and 358 cm of air for the other one. The data were recorded by a 16-

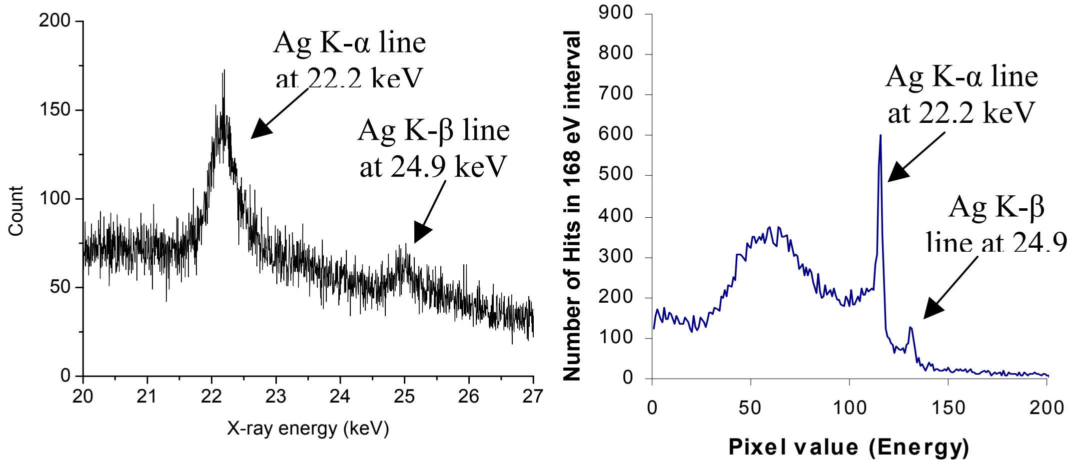

Figure 1: Typical K-alpha/K-beta spectra taken by the two single hit CCD cameras show clearly measurable K-alpha and K-beta peaks.

bit, 1340x1300 Princeton Instruments x-ray CCD. Additionally, the plasma blow-off from the target was observed by an XUV multilayer imager at 68.8 eV. The Si/C/Mo multilayer spherical mirror has a curvature of 308 mm and in the given set-up provides an 11.5x magnified image of the top-, backside of the target.

Experimental Results

The spectra were measured in terms of time- and space-integrated yield from the whole target. The spectra enable to distinguish and measure the yield of both K-α and K-β lines (Fig. 1). The spectral resolution can be evaluated from the apparent line width at full-width half-maximum of the K-alpha line (for our purposes considered a delta function) and was hence measured on the order of ~500 eV. This resolution is adequate for our K-α study, but would not enable to study fine structure or K-α line shifts due to enhanced ionization.

The intentional long prepulse was focused to a 1-mm diameter spot to overfill the target and create large uniform 1-D gradient plasma. The prepulse varied from 10^9 W/cm^2 (comparable to the inherent prepulse) to 10^{12} W/cm^2 by varying the long pulse laser energy. The K-α yield was measured to be constant within the experimental precision and equal to ~10^{10} photons.

The angle was varied from “normal” incidence at 15.5±0.8° through 45° to “grazing” incidence of 70° as measured from the normal to the target. Also in this case the yield did not show significant variations.

The plasma blow-off was observed on a shot-to-shot basis using a time-integrated crystal imager at 68.8 eV (Fig. 2). With no prepulse applied, the plasma – in accordance with the model – starts off forming a hemispherical shape around the laser spot incident on the target and then continues to grow in the direction of the highest electron density gradient (Fig. 2 a, b, c). The images also indicate that a part of the laser energy, probably as converted to hot electrons, is, for small size targets, drained to the target supporting plastic fiber and the target mount could therefore influence a more precise measurement outcome in various types of experiments.

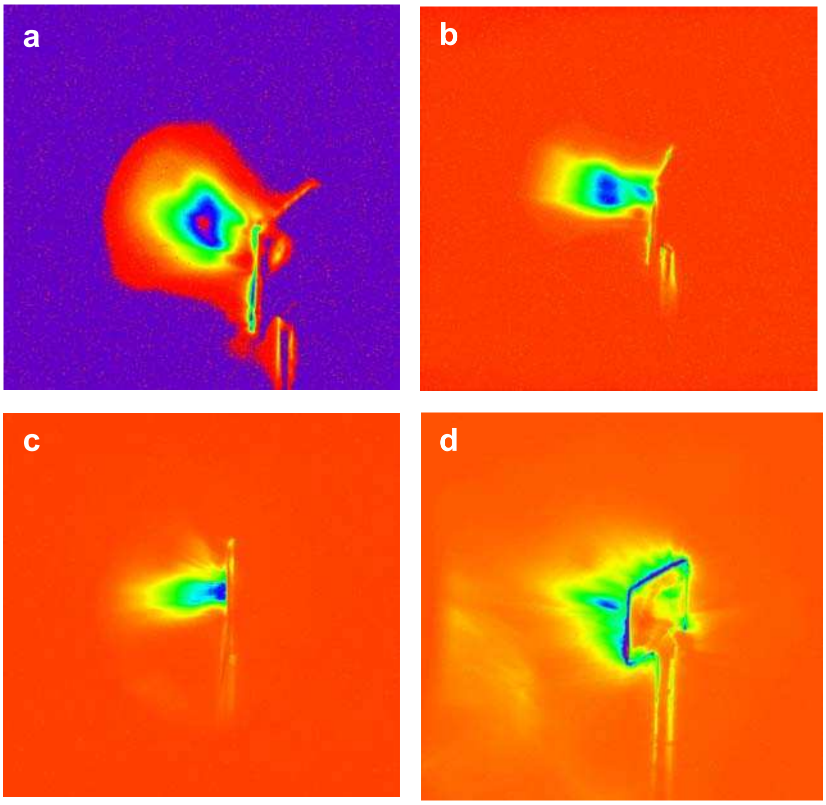

Fig. 2: XUV image at 69 eV of the plasma blow-off from a square, 500x500x50-um Ag targets attached on a CH fibre at interaction with a 10^{19} W/cm^2 Vulcan pulses. (a) "normal" incidence, (b) 45-deg incidence, (c) 70-deg incidence (side view on the picture) and (d) the normal incidence with a "flat" 10^{12} W/cm^2 intentional prepulse

The intentional prepulse overfilling the target produces, however, a significantly different plasma preplasma regime: a 1D layered preplasma covering the front surface of the target. The main laser pulse then interacts at normal incidence with thus preformed plasma (Fig. 2d) as evidenced by the XUV imager. In this case, a variation in the angle of incidence for the main pulse would probably introduce a different laser light absorption mechanism and therefore influence the K-alpha conversion efficiency. In our experiment, however, the incident angle was kept constant when varying the intentional prepulse and therefore this effect cannot cause variation in K-alpha yield.

Discussion

In order to evaluate the inherent preplasma conditions in our experiment a series of LASNEX [4] numerical simulations have been carried out. For a typical laser spot size of ~10 um and the inherent prepulse at the level down to 10^{10} W/cm^2, a substantial cold preplasma is generated. The preplasma forms a hemisphere with the scale-length on the order of the spot size as is also easily shown by the full numerical simulation. Similar preplasma characteristics were also shown experimentally at GMII laser [3]. The intentional experimental prepulse and/or the main laser pulse then therefore interacts with a hemisphere of the plasma just in front of the target surface, rather than with the solid target itself.

Another effect in our experiment that may play an important role to form the plasma profile is associated with the short (10-ps) intense (10^{18}-10^{19} W/cm^2) main laser pulse, namely its radiation pressure that is significantly larger than the plasma pressure. In our experiment the radiation pressure is approx. 3 orders of magnitude higher (3×10^{14} Pa = 3 Gbar) than the plasma pressure (3×10^{11} Pa = 3 Mbar). This simple calculation shows that even the beginning of the main pulse with a small fraction of the total laser energy can modify the plasma profile. The plasma density profile, ie. the scale-length – is hence steepened through the ponderomotive force of the incident high intensity laser pulse, as experimentally evidenced by Liu and Umstadter [5] even for intensities as low as ~10^{15} W/cm^2. The scale-length is therefore defined by the main laser pulse parameters and remains roughly constant over a wide range of preplasma scale-lengths. A simple analytical evaluation shows that the scale-length is reduced by the ponderomotive force on the order of $L \approx 0.1$ μm independent of the original scale-length over the parameter range studied in the experiment.

Acknowledgment

We would like to thank to the laser crew of the VULCAN laser facility for their excellent service during this experimental campaign. This work has been performed under the auspices of U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

References

[1] K. B. Wharton et al., Phys. Rev. E 64, 025401(R) (2001).

[2] S. C. Wilks, W. L. Kruer et al., Phys. Rev. Lett. **69**, 1383 (1992);

[3] K. Adumi et al., Phys. Plas. 11,3721 (2004)

[4] G. B. Zimmerman and W. L. Kruer: Com, Plas. Phys. Cont. Fusion **11**, 51 (1975)

[5] X. Liu and D. Umstadter, Phys. Rev. Lett. **69**, 1935-1938 (1992)