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Photodiodes array as potential diagnostic for measuring short bursts of K-α radiation from Ti targets irradiated with 45 fs laser pulses

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Abstract

We report on a study comparing absolute K-α yield from Ti foils measured with a calibrated system of an X-ray CCD coupled to a curved LiF Von-Hamos crystal spectrometer to the difference in the signals measured simultaneously with two similar photodiodes fitted with two different filters. Our data indicate that a combination of photodiodes with different filters could be developed into an alternative and inexpensive diagnostic for monitoring single shot pulsed emission in a narrow band of X-ray region.
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1. Introduction

The generation of short bursts of K-α radiation emitted from solid targets irradiated with sub-picosecond laser pulses has been a subject of interest to a myriad of researchers e.g. [1–9]. Such radiations—due to their source compactness, narrow line-width, and short pulse length—have got potential applications in various fields such as crystallography [10], medical science [11], etc. The level of absolute K-α radiations from laser produced plasmas is measured mostly with delicate X-ray CCD coupled to a crystal spectrometer. In some cases, the X-ray emission is spectrally resolved and focused onto a diode with a curved crystal [7]. Such CCD systems are prone to thermal noise generation which is overcome by cryogenic cooling of the CCD chip. This adds to the complexity of an experimental set-up. Most of the crystals employed in such experiments are either having low reflectivity or expensive and/or complicated in use. Furthermore, our previous spectrally resolved results [12] have shown that the K-α signal is always superimposed on a background of hard X-rays, either due to bremsstrahlung radiation from the target or fluorescence from the crystal substrate. The signal from a single diode alone, with the combination of a curved crystal, will thus also carry a contribution of the background hard X-rays. The level of such hard X-ray background needs to be monitored for each shot. One would need to use a second diode, in such cases, to record the background level that could be used to deduce the K-α signal. We report on an experiment where we simultaneously employed a calibrated X-ray CCD system coupled with a Von-Hamos crystal spectrometer to monitor the absolute level of K-α radiation from Ti foils as well as an array of two photodiodes fitted with two different filters. Our results indicate that an array of two diodes with proper filtering, without the aid of any focusing crystal, could be developed into an inexpensive and easy to use diagnostic for the absolute measurement of single shot K-α radiation from laser produced plasmas.

2. Experimental Set-up

We used the short pulse laser facility, ASTRA, at the Rutherford Appleton Laboratory, capable of delivering up

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to 500 mJ, infrared (800 nm), p-polarized pulses of 45($\pm$5) fs duration. The main pulse is accompanied by a pre-pulse ($\sim$13 ns ahead of the main pulse and having a contrast of 10^{-7}), an uncompressed CPA pedestal and ASE. The contrast of the residual uncompressed pedestal is measured to be 10^{-6} at 10 ps and rises to 10^{-4} at 1.5 ps ahead of the main pulse. The ASE starts 2 ns ahead of the main pulse and rises linearly from a background of 10^{-8} of the main pulse to a level of 10^{-6} in 1 ns and then stays constant until the main pulse arrives. An f/2.5 off-axis gold-coated parabola was used to focus the IR beam at an angle of 20° and 45° normal to the target plane, as shown in Fig. 1. Focal spots at different positions were recorded in the low-energy mode of the laser with the help of a retro-system. Details of the experimental setup are published elsewhere [13]. The full-width at half-maximum (FWHM) of the focal spot at the best focus was measured to be $3 \times 3\,\mu$m containing about 55% of the total energy. The focal spot was varied by moving the parabola off the best focus position along the line-of-focus by a known amount with the help of a micro-controller, towards the target and away from the target (referred to as positive off-set and negative off-set, respectively). With the positive off-set a convergent beam interacts with the target while in case of the negative off-set the focus lies before the target and a divergent beam interacts with the target. As we go off the best focus, the focal spot starts breaking up into numerous hotspots and, therefore, the energy distribution in the focal spot changes. The energy on target was monitored for every shot with a calibrated system of a fast diode and the maximum energy recorded on target was $\sim$150 mJ. At the best focus, the intensity on target reaches a maximum of $\sim 10^{19}$ W/cm^2. Ti foils having thickness of 12.5 μm were used as target. After every shot, the target was moved by 2 mm with an external computer controlled micro-drive to get a fresh surface of the target for the laser interaction. In all cases, the beam was tight focused on the foil, using a retro viewing system, before moving the parabola to the desired offset position.

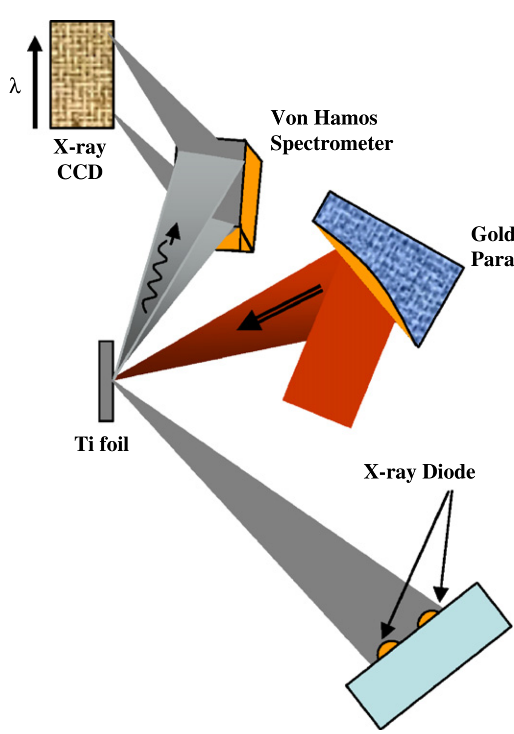

Fig. 1. Schematic layout of the experimental set-up inside the chamber.

The time integrated absolute yield of K-α line emission from titanium (4510.84 eV), was recorded with a calibrated system [9] employing an X-ray CCD and a curved LiF (2 0 0) crystal with a reflectivity of 0.042 mRad. The line of sight of the spectrometer (crystal centre and the source position) made an angle of $\sim$48° with the horizontal plane. We also used two silicon p–n junction photodiodes (AXUV-series) from International Radiation Detectors Inc (IRD), one filtered with 12.5 μm Ti and the other with 100 μm Al filter to record the X-ray signal. These are highly efficient large area ($\sim$1 cm^2) photodiodes exhibiting very low noise and are insensitive to magnetic field. The quantum efficiency of these diodes, defined as the number of electrons seen by the external circuit per incident photon, varies linearly with the energy of the incident photon. Both these diodes were placed inside the vacuum chamber at a distance of $\sim$44 cm from the target and their output fed into a fast digital oscilloscope through a 50 Ω terminator for monitoring the signal. The peak of the signal on the scope was used to measure the level of the signal.

3. Results and discussion

In Fig. 2 we have plotted the difference in the percentage transmission of two filters versus the energy of the X-ray photons in the region 2–10 keV. In the set of filters, shown as solid line, one filter is 12.5 μm titanium (Ti) and the

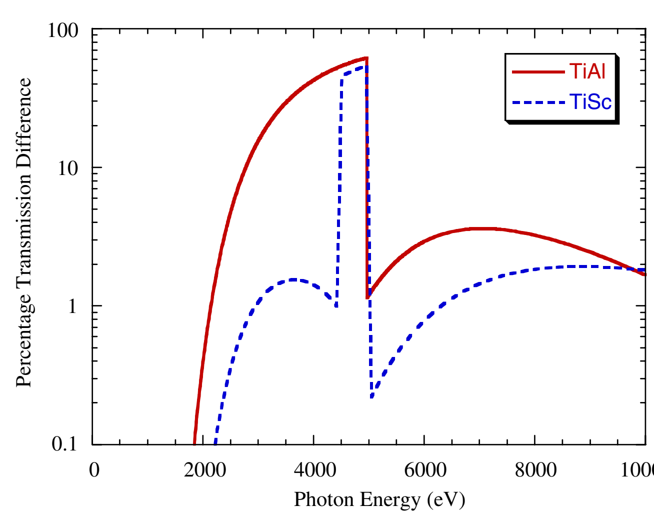

Fig. 2. Plots showing difference in percentage transmission of two sets of filters versus the energy of the X-ray photon in the range of 2.0–10.0 keV. The solid line represents the set of 12.5 μm of Ti and 100 μm of Al. In the second set, shown as dotted line, one filter is 16 μm of Ti and the other is 28 μm of Sc.

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