Fast Electron Transport Studies in Petawatt Laser Irradiation of Solid Dielectric and Metallic Target Materials

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Introduction

The detailed knowledge of the fast electron generation and transport mechanisms in high-intensity short-pulse laser-solid interactions is of fundamental importance for the fast ignition approach to inertial confinement fusion, where ultra-high current relativistic electron beams will have to propagate through an outer low Z plasma layer in order to deposit their energy in the core of the fusion pellet, creating a hot spot and such igniting the fuel [1].

A typical experimental approach to the study of fast electron transport is the irradiation of multilayer target foils [2]. The main diagnostics in these experiments are based on X-rays emitted from the different target layers, but also direct measurements of the electrons leaving the target foil and optical transition radiation measurements are employed. Much progress has been made in the past year in the understanding of the fast electron transport phenomena. Nevertheless, there are still open questions concerning e.g. return current issues [3], instability growth and lateral fast electron transport [4].

The joint experiment, that we will describe here, was carried out within the HiPER project at the Target Area Petawatt (TAP) of the VULCAN laser facility at RAL. It was designed for a systematic study of fast electron energy transport in different target materials for interaction conditions that are of interest for the fast ignition case.

Experiment

The idea of the experiment was the investigation of the transport of the energetic electrons in the target material, with particular attention to differences of the electron transport in conducting/dielectric materials with similar atomic number Z and in dielectric target materials with different Z.

Therefore, sets of multilayer targets containing a metallic (Al) or a dielectric (SiO_2 or plastic) propagation layer respectively, have been used. The first set of targets, the so-called thick targets, consisted of two layers each. The laser-irradiated layer was made of Al, SiO_2 or plastic of two different thicknesses (25 µm or 50 µm), while the second layer, that is the tracer layer, consisted of 1 µm thick Cu. The transverse dimensions of these targets were some mm^2. The second set of targets, the so-called mass-limited targets, were made of three layers and had transverse dimensions of 400 µm x 400 µm. The laser-irradiated layer was made of Al, SiO_2 or plastic respectively, with thicknesses varying between 1.6 µm and 4 µm. The second layer, made of 1 µm thick Ni, was the tracer layer and the last layer consisted of 1 µm thick plastic material.

The VULCAN petawatt laser beam used in the experiments has a pulse duration of about 500~fs. The beam is focused by means of an off-axis parabola (f/3) to a slightly elliptical focal spot of 6 µm x 4 µm size, in which 50 % of the compressed energy, that means 135 J in this experiment, is contained. The intensity on target is therefore about 10^{21} W/cm^2.

A variety of diagnostics have been set up in the experiment, including shadowgraphy/interferometry, Optical Transition Radiation measurements, back and front side X-ray pinhole-cameras, 2D monochromatic imaging of the X-ray line emission with a bent Quartz crystal and high resolution X-ray spectroscopy with a bent Mica crystal spectrometer. In some of the experimental shots, in addition to these diagnostics, forward accelerated electrons and protons were detected by means of a custom-made detector called SHEEBA [5]. The detector has been used in direction of the laser beam as well as in the direction normal to the target surface.

Preliminary results

Preliminary experimental results from the thick targets and from the mass-limited targets will be presented, with particular attention to the X-ray emission measurements.

In the case of the thick targets, containing a front propagation layer made of different materials (Al, SiO_2 or plastic) and a Cu tracer layer, Kα line emission generated by the fast electrons in the copper tracer layer was characterized spectrally and spatially. For all target types, the FWHM of the Kα emission region was measured to be around 80 µm. This value has to be compared to the focal spot size of about 5 µm diameter and the spectrally integrated plasma X-ray emission spot size detected with the use of an X-ray pinhole-camera of around 20 µm diameter. Concerning the Kα emission intensity, a significant enhancement of Cu Kα radiation was observed from the irradiation of targets with the SiO_2 propagation layer, whereas no such an enhancement was observed for the targets with the plastic or the Al propagation layer. These experimental observations will be discussed, taking into account the data obtained from the other diagnostic devices employed in the experiment.

The mass-limited targets contained the same propagation layer materials as the thick targets (SiO2 ,Al or plastic) and a Ni tracer layer. In this case, the monochromatic imaging crystal was tuned to reflect the Ni Lyα line. The spectral range observed with the high-resolution X-ray spectrometer contained the Ni Lyα lines and other emission lines from highly ionized Ni atoms. The X-ray spectra give information about the electron temperature and density in the Ni layer at a depth of a few micron from the laser-irradiated front surface. X-ray spectra were calculated with the FLY code suite for a range of electron densities and temperatures and then compared to the experimental data. The results indicate plasma temperatures in the keV range.

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