Study of Fast Electron Dynamics in Solids Using Multispectral, Monochromatic X-ray Imaging

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1. Introduction

The issue of transport of high-current beams of relativistic electrons in solid matter or high-density plasmas is currently receiving a major attention due to its importance for the fast-ignition approach to the Inertial Confinement Fusion. In particular, from the experimental viewpoint, a major effort is ongoing to develop novel experimental techniques allowing to trace the electron propagation in near solid-density matter, while from the theorethical/numerical viewpoint, new hybrid codes for the simulation of the electron transport are currently being developed. Here we will report on the results of two recent experiments, performed in the framework of the activity for the "HiPER - **Hi**gh **P**ower laser **E**nergy **R**esearch facility" project, in which a new experimental technique was used to study the propagation of fast electrons through the target in relativistic laser-matter interactions.

1. Experimental setup and outline of the technique

Figure 1 shows schematically the typical experimental setup, used, with minor changes, in both the experiments. As shown in the Figure, the technique is based upon the use of a pinhole camera equipped with a CCD detector forced to work in the single-photon regime by means of suitable X-ray attenuators. As it is well known, when used in the single-photon regime, a CCD detector enables the spectrum of the impinging radiation to be obtained without any additional dispersive device.

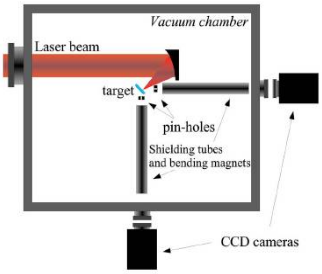

Fig. 1. Layout of the experimental setup

In our case the pinhole consisted either of a single 5μm diameter pinhole or of an array of 20x20 pinholes with typical diameter of 4-6μm. The technique allowed X-ray images to be obtained (on a single-shot base in the latter case and on a multi-shot base in the other case) which are resolved in energy (δE=150eV) over a large photon energy range, namely from a few keV up to some tens of keV. The magnification was in our case M=10 and the spatial resolution of the images was of about 5μm (on the object plane). Two different single-photon pinhole cameras were set to look at the target from the front and the rear side respectively.

3. Overview of the main results and discussion

Two different short pulse laser interaction regime have been investigated, namely a relatively long, moderate intensity (~200ps, I=10^{16} W/cm^2) and an ultrashort, relativistic intensity (~70fs, I=$5x10^{19}$ W/cm^2) regime. In both cases, the fast electron transport was studied by looking at the X-ray emission (both $K\alpha/\beta$ and Bremsstrahlung) from specially designed, multi-layer targets. Indeed, as it is well known, K-shell emission can be fruitfully used as a diagnostics for the fast electron propagation. In general, multilayer targets are usually employed in order to distinguish the X-ray emission at different depths inside the target. As an example of the different target used, we consider in this sinopsis a three-layer target consisting of Cr 1.2 mm thick layer on the front side, a middle layer of Ni, 11 mm thick, and a third layer (on the back side) of Fe of thickness of 10 mm in the ultrashort, relativistic case. Figure 2 *top* shows the images of the X-ray source at the $K\alpha$ and $K\beta$ line energies (that is, considering both Ka and Kb photons) of the three target layers. The K-shell emission from each of the three layers has been used to reconstruct the propagation of the fast electron beam through the target. In particular, this was done by comparing the experimental results with numerical simulations of the fast electron propagation performed with the hybrid code PETRA [5]. The initial fast electron distribution was obtained by means of PIC simulations.

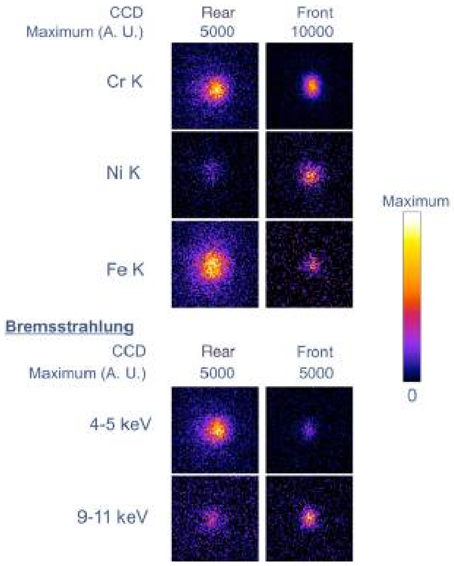

Fig. 2. *top:* X-ray images of the source at the $K\alpha$ and $K\beta$ energies (considered together) of the different target materials, obtained from 350 shots on a Cr-Ni-Fe target. *bottom:* images of the X-ray sources at energies where no emission lines is expected (i.e., in energy ranges where only Bremsstrahlung emission can be expected). The image size is 156μm (in the object plane) in both the horizontal and vertical directions.

An interesting feature of the images in Figure 2 *top* is the noteworthy difference in the X-ray source side *at the same energy* when viewed from the front and from the rear side of the target. This feature should possibly arise from a non-isotropic X-ray emission process, such as the Bremsstrahlung from the fast electron propagating inside the cold or partially ionized target [6]. This mechanism has been studied in our case and will be also presented.