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K-α Emission from Multilayer Targets Irradiated by Ultrashort Laser Pulses

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1. INTRODUCTION

Ultrashort pulse-produced laser-plasmas are promising sources of short wavelength radiation. K-α radiation is of particular interest as the emitted energy may be comparable with the most intense resonance lines and the pulse length may be considerably shorter [1].

Multilayer targets can be applied to separate K-α emission induced by fast electrons in cold matter from the emission of hot plasma on the target surface. Moreover, hot electron temperature may be deduced from the dependence of K-α emission energy on the surface layer thickness. Influence of surface plastic layer on the hot electron transport and on K-α emission is studied here numerically. Comparison with recent experimental results [2] is presented.

2. SIMULATION TECHNIQUE

Fast electron transport and K-α emission from multilayer targets is studied here by means of 3D MC (Monte Carlo) simulations. Our code [1] is specially tailored for simulation of K-α emission and it was adjusted to calculate energy deposition and fast electron current density in the target with spatial and temporal resolution. This allows us to make estimates about the magnitude of the self-induced resistive electric field, which may radically influence fast electron transport in dielectrics. The code is then able to apply preassigned electric field parallel with the fast electron beam, which decelerates electrons propagating inside the target and finally accelerates electrons propagating outside.

In the present work, we assume multilayer targets composed of 4 μm aluminum layer deposited on bulk silicon wafer and covered by thin surface plastic layer [2]. The input for our MC calculations are either fast electron distributions from our 1D3V PIC simulations [1], or Maxwellian or relativistic Maxwellian [3] distribution is assumed, and a search for the hot electron temperature is performed.

3. RESULTS AND DISCUSSION

In the experiment [2], 50 mJ 100 fs Ti:Sapphire laser pulse was incident on the targets either at an angle of 40° (p-polarization) with peak intensity of 2×10^{16} W/cm^2 or normally with peak intensity of 4×10^{16} W/cm^2. The contrast ratio of ASE (Amplified Spontaneous Emission) 1 ns before the main pulse was better than 10^{-6} and no intentional prepulse was applied. The surface plastic layer was vapor deposited 6FDA/TFDB polyimide.

The fast electron distributions, input for our MC simulations, were calculated by PIC code assuming laser incidence angle 40° and relatively short plasma density scale lengths in the range 0.05-0.1λ. These scale lengths are estimated in view of moderate laser intensity, high contrast ration and high transparency of polyimide to low intensity infrared radiation. The calculated fast electron spectra are presented in Fig. 1. The relativistic Maxwellian distributions, which are included in Fig. 1, are the best fits to the experimental K-α yields.

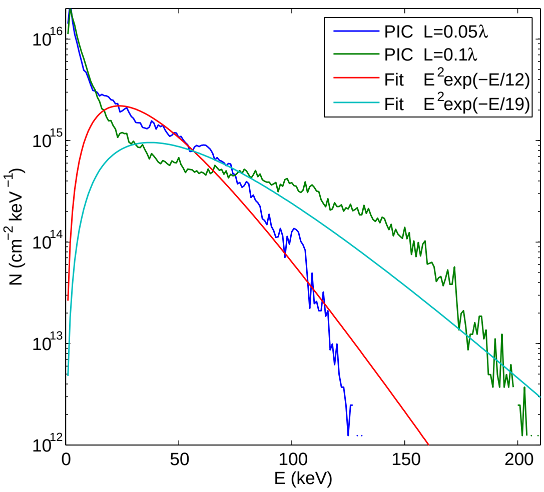

Fig. 1: Fast electron energy spectra calculated by PIC code for p-polarized laser of intensity 2×10^{16} W/cm^2 incident at the angle 40° on plastic plasma with mean ion charge 2, initial temperature 100 eV and exponential density profile with the respective scale lengths L. The two relativistic Maxwellian distributions are the best fits to the experimental K-α emission yields, as described below.

MC K-α emission results are compared to the experimental data in Fig. 2. A strong decline in K-α emission intensity was evidenced in the experiment in the case of oblique incidence, when the thickness of polyimide layer increased from 0.3 to 4.2 μm. While the source of fast electrons appears similar or even less efficient for obliquely incident laser when thin polyimide layer is added, K-α emission was about twice enhanced for normal incidence and this signifies that the fast electron generation is more efficient in this case. Tentative explanation of this effect is that the ASE causes some damages on the initially flat polyimide surface and the main laser pulse interacts rather with rough than a flat surface. Drilling of an epoxy polymer layer on the surface of copper target was observed at intensities as low as 10^8 W/cm^2 with 15 ns Nd:YLF laser pulse [4]. The roughness of target surface does not change fast electron generation in the oblique incidence case significantly, but a significant enhancement of fast electron generation for normally incident laser pulse was observed in experiments [5]. Moreover, we expect that for short plasma density profile even a small roughness of order several nm may be significant.

A weaker decrease in the emitted K-α energy with polyimide layer is observed for normal incidence. Also, the emitted energy for 0.3 μm thick polyimide layer is 1.4 times enhanced in comparison to oblique incidence. This is partly caused by twice higher laser intensity used in the case of normal incidence. Due to higher intensity, we have also estimated the density scale length is greater, i.e. L=0.1λ. We have therefore roughly approximated the fast electron distribution in this case by PIC results for oblique incidence and the above parameters.

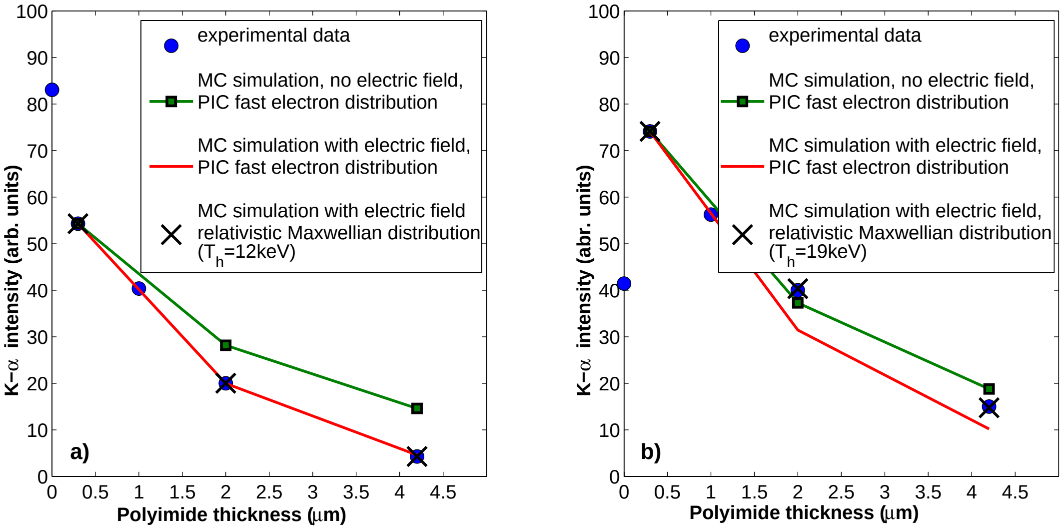

Fig. 2: Comparison of the experimental dependence of K-α intensity on the thickness of the surface polyimide layer with MC simulation results with and without application of 8 kV/μm resistive field in polyimide layer. In part a) results for oblique incidence are presented and PIC fast electron spectra was calculated with L=0.05λ. In part b) the results are for normal incidence and the PIC fast electron spectra was calculated with L=0.1λ.

In Fig. 2 a) experimental data for oblique incidence are compared with our MC simulations with PIC fast electron spectra, L=0.05λ. It demonstrates that the purely collisional MC model cannot reproduce the experimental decrease of K-α emission. Fitting the experimental data with MC simulations and Maxwellian distribution of fast electrons, leads to estimate of $T_h \simeq 8$ keV ($T_h \simeq 5$ keV for relativistic Maxwellian). Firstly, this temperature seems to be too low, secondly this fit is still not reasonably accurate in the whole range of the used polyimide thicknesses. We suppose than the strong decrease of K-α emission is due to resistive electric field induced in the polyimide layer, which inhibits propagation of slower fast electrons into aluminum layer. Serious influence of resistive electric field in surface plastic layer on the fast electron transport was evidenced experimentally for laser intensities of the order 10^{16} W/cm^2 [6]. To estimate the resistive electric field, we used fast electron distribution from PIC simulation, calculated electron beam current density in the polyimide and estimated the resistivity of polyimide to 10^{-5} Ωm, according to the value published in [7] for polystyrene compressed and heated by a shock wave to about 1 eV. As our fast electron current density was of the order 10^{15} A/m^2 [8], we added in MC simulations a homogeneous electric field of 8 kV/μm normal to the target surface. Our estimates of the resistive electric field are described in [8]. When the electric field of 8 kV/μm was applied in polyimide, our results are in a good agreement with experimental observations. We also performed a series of MC simulations with relativistic Maxwellian distributions and the best fit to the experimental data was found with the electric field and electron temperature T_h=12 keV. This distribution is similar to our PIC result for L=0.05λ. Our results for normal incidence, Fig. 2 b, are not as accurate as for oblique incidence, even when the resistive electric field is applied. The best fit to the experimental data was found for relativistic Maxwellian electron distribution temperature T_h=19 keV.

4. CONCLUSIONS

K-α emission from aluminum target covered by a surface plastic layer is calculated by MC code using fast electrons resulting from PIC simulations. The value of self-induced resistive electric field in the plastic layer as high as 8 kV/μm is estimated from the fast electron current density and the resistivity of plastic material. The effect of such field on K-α emission from the target front side is demonstrated. The experimentally observed decrease of energy of K-α radiation emitted from inner metallic layer with the thickness of the surface plastic layer may be used for estimation of the self-induced electric field in dielectrics.

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