GA–A27182

INVESTIGATION OF LASER TO ELECTRON ENERGY COUPLING DEPENCDENCE ON LASER PULSE DURATION AND MATERIAL COMPOSITION

ANNUAL REPORT TO THE U.S. DEPARTMENT OF ENERGY FOR THE PERIOD FEBRUARY 1, 2011 THROUGH OCTOBER 31, 2011

by
PROJECT STAFF

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DISCLAIMER

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GENERAL ATOMICS

1 INTRODUCTION

Objective Summary for the two-year grant:

- Generate information on energy absorption and transport through the cone tip and its dependence on the cone material, laser energy, pulse length, and pre-pulse energy to optimize the design of Fast Ignition targets
  - Transport dependence with target material and pulse length (10 ps versus 1 ps) was done for flat surfaces in this reporting period; cones are scheduled for the next one.
- Compare the results of planar multilayer targets with embedded-cone targets
  - Will be done after cone campaign in 2012
- Compare the results with predictions from multi-dimensional Particle-In-Cell (PIC) numerical simulations
  - Reduction in fast electron flux and angular spread with 1 ps laser pulse is consistent with the 2D collisional PIC simulation results. Simulations of laser plasma interaction and fast electron transport at 10 ps pulse duration are underway for flat surfaces.
- Provide graduate student training in the area of high intensity laser-matter interactions
  - Ongoing – lead grad student Anna Sorokovikova, UCSD

2 DISCUSSION OF ACCOMPLISHMENTS

Efficient conversion of laser energy to hot electrons and their subsequent energy transport to the compressed fuel are extremely important for the success of fast ignition to reduce the cost of ignition pulse. Energy coupling is controlled by the nature of the plasma (i.e., density profile, ionization etc.) at the laser-plasma interface and the dynamic response of the transport material, which evolve with time, therefore dependent on laser pulse length. Previous experiments [1] performed on the Titan laser (0.7 ps pulse length, 150 J) at Lawrence Livermore National Laboratory (LLNL) showed that 10 μm high-Z material in the multilayer planar solid target suppresses fast electron angular spread and reduces the forward going fast electron flux. The goal of the General Atomics (GA) National Laser Users Facility (NLUF) project is to further investigate target material effects on fast electron transport and extend such a study to 10 ps time scale at high intensity using the kJ OMEGA EP laser.

The project consists of two steps:

1) Characterize fast electron generation and transport through different transport materials using 1 ps laser pulses with 300 J energy to compare with the Titan experiments in both planar and buried cone geometry.
2) Extend the planar and buried cone studies to 10 ps with 1.5 kJ energy.

Our two OMEGA extended performance (EP) shot days in FY11 (Ecoupling-11A and -11B on 8 June, and 17 August, respectively) were used to look at the dependence of fast electron transport on target material and pulse length for the planar geometry using multilayer planar foil targets. The targets and setup were the same for the two experiments (Fig. 1).

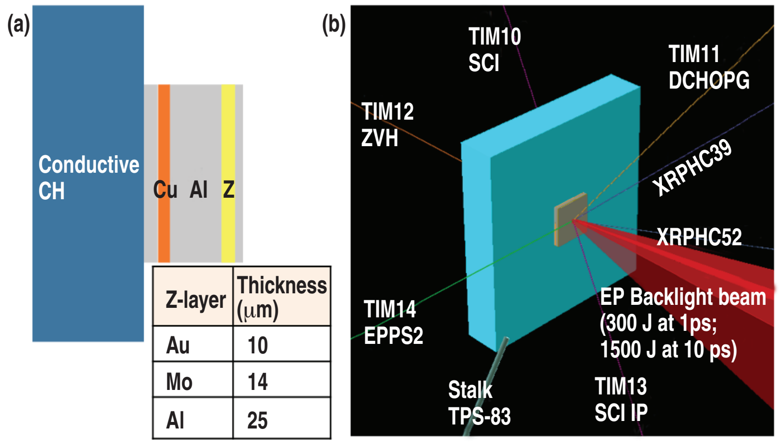

Fig.1 Schematic of the (a) multilayer plannar foil target and (b) experimental setup.

The high intensity short pulse EP backlight beam (300 J at 1 ps for the first day, 1500 J at 10 ps for the second) was tightly focused (80% of laser energy in a 50–60 μm focal spot). The 1×1 mm^2 multilayer target consisted of a front surface Al layer (4 μm) over a thin transport layer (~10 μm) of various Z materials (Au, Mo and Al), an Al spacer (75 μm), a Cu tracer layer (12 μm) followed with a 20 μm thick Al layer. It was backed with a 1 mm thick 5×5 mm^2 wide conductive plastic layer to minimize electron refluxing. Fast electrons were characterized by two primary diagnostics, i.e., a spherical crystal imager (SCI) to measure the spatial distribution of fast electron induced 8 keV fluorescence radiation in the Cu trace layer and a Zinc Von Hamos (ZVH) x-ray spectrometer tuned for measurement of the absolute Cu-$K\alpha$ yield, which is proportional to the fast electron flux in this single pass target.

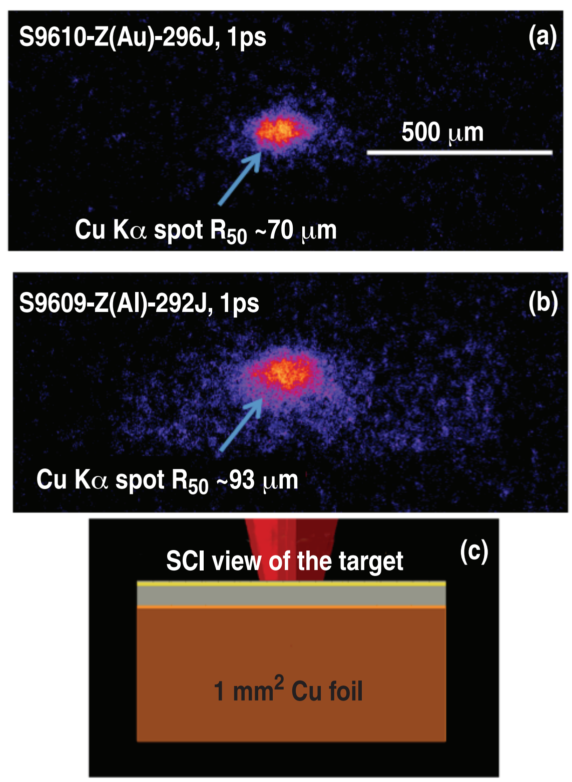

Figure 2: SCI recorded Cu-$K\alpha$ radiation spots in 1 ps interaction experiment: (a) with a $Z = Al$ transport target; (b) with a $Z = Au$ transport target; (c) SCI diagnostic view of the target. Images (a) and b) are with same color and spatial scales. A smaller $K\alpha$ spot is observed in $Z = Au$ transport targets.

In the 1 ps EP laser interaction experiment, we observed a smaller Cu-$K\alpha$ fluorescence spot with the high-Z Au transport target compared to the Al transport target with good reproducibility. As shown in Fig. 2, the measured Cu-$K\alpha$ spot in Z=Au case is about 70 μm in radius (R_{50} is the radius of the spot counting all the pixels with signal ≥ the peak value) and 93 μm for the $Z = Al$ target case, which is consistent with the previous Titan results [1]. 2D collisional PIC modeling including dynamic ionization and radiation cooling suggest strong resistive magnetic fields inside the high-Z transport target collimate fast electrons and reduce forward-going fast electron angular spread [2] (Fig. 3).

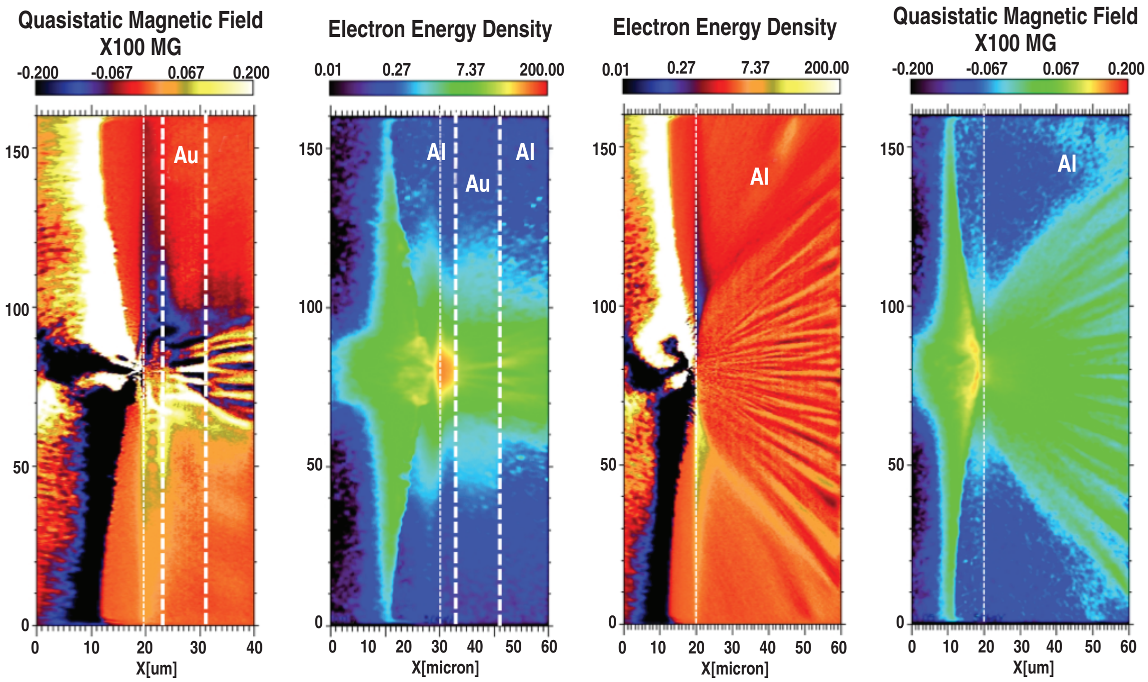

Figure 3: 2D PIC simulations show electron transport partially collimated due to strong B-fields generated by the addition of an 8 μm thick Au transport layer in an Al target. The magnetic fields (a) and electron energy density (b) for the buried Au case are compared to the fields and electron energy density for the pure Al case {(c) and (d)} at the end of the laser pulse (Gaussian in time and space, fwhm 730 fs long, fwhm10 μm diameter, $I_{max} = 9 \times 10^{19} W / cm^2$).

Experiments with 10 ps, 1500 J EP pulse however showed a large shot-to-shot variation with very different behavior of laser produced fast electrons and their transport as evidenced in the observed $K\alpha$ spots compared to the experiments with 1 ps as shown above. Figure 4 shows the SCI recorded Cu Kα images from three different types of Z transport targets. It is evident that there are pronounced filamentary structures [Fig. 4 (a), (b)] and irregular shapes [as shown in Fig. 4(d)] in the fluorescence spot. With identical $Z = Al$ targets, we observed 2–3 filaments with a separation distance of ~100 μm, which suggest the growth, of widely separated, stable filaments after a few ps, either in the laser plasma interaction region or inside the solid target. PIC modeling is underway to study high intensity laser plasma interaction (LPI) and fast electron transport in 10 ps time scale.

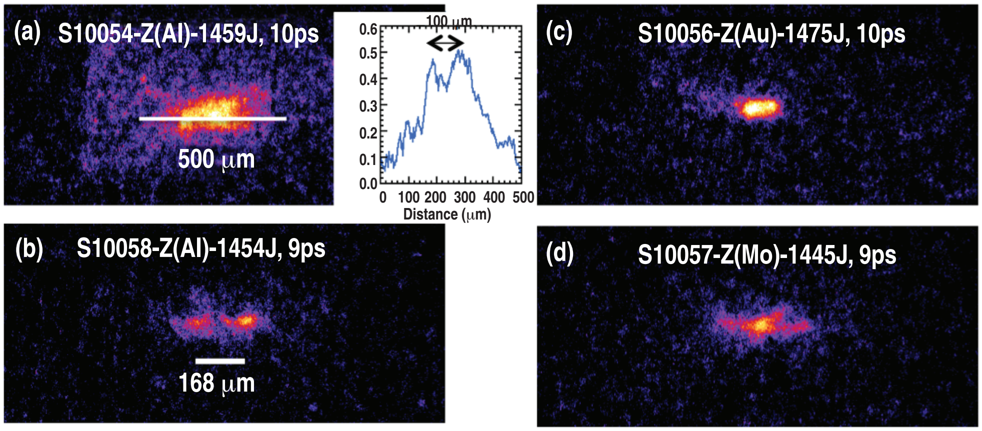

Figure 4: SCI recorded Cu-$K\alpha$ radiation spots in 10 ps interaction experiment: (a) and (b) with $Z = Al$ transport target, lineout of a) is shown in the inset; (c) with $Z = Au$ transport target and (d) with $Z = Mo$ transport target. Images are with same color and spatial scales. Filamentary structures and irregular shapes of fast electron beams can be clearly seen with large shot to shot variation.

3 SCHEDULE STATUS - CHANGE IN APPROACH

The first year's shots occurred on 8 June, and 17 August 2011. The second year's shot days (28 and 29 February 2012) will enable further experimental investigation. On the first day, we will further investigate the 1 ps versus 10 ps LPI using the same target as the first year but with two additional hard x-ray bremsstrahlung x-ray spectrometers, together with SCI and ZVH, to fully characterize fast electron source and transport phenomena. The second day will use buried cone targets.

4 PUBLICATIONS/PRESENTATIONS

[1] M.S. Wei, "Investigation of dependence of laser energy coupling on target material and preplasma scalelength for reentrant cone guided fast ignition laser fusion," (Invited talk) presented at the 38th EPS Conference on Plasma Physics, Strasbourg, France, June 27 through July 1 (2011).

[2] R. Mishra *et al.,* "PIC modeling of material dependence on fast electron generation and transport," presented at the 7th International Conference on Inertial Fusion Sciences and Applications, Bordeaux, France, September 12–16 (2011).

5 COST STATUS

We've spent $39,365.70 out of the first year's installment of $75,013. We are currently ramping up a substantial analysis effort that is increasing spending rate substantially. We expect expenses at the end of our first year to be near $60K. The second year's experimental campaign is scheduled for 28 and 29 February 2012. That campaign plus the analysis and presentation of our complete effort will require the total planned expense of $150,026 for the two years of this grant.