Fast electron generation and transport in solid targets

Paul McKenna
University of Strathclyde
Talk summary

1. Fast electron generation and transport in ultraintense laser-solid interactions

2. Transverse refluxing of fast electrons in thin foil targets

3. SUSSP Laser-plasma summer school
Laser absorption to fast electrons:

Processes identified in the literature:
Brunel; vacuum heating, wave breaking, stochastic heating, anomalous skin layer absorption, anharmonic resonance, ponderomotive vxB,.....

Sensitive to:
- Pulse duration;
- Polarisation;
- Pulse intensity;
- Angle of incidence;
- Focal spot size;
- Preplasma expansion;
- Target Z.

Complex picture!

Experimental results to test / benchmark models of absorption
Specularly reflected laser light

Generally higher absorption with longer scale length plasma

Region of high laser energy absorption

Two distinct absorption processes?
Proton and Cu Kα measurements

- Proton and Cu Kα measurements are shown in the graphs.
- Graphs illustrate the dependence of maximum energy $E_{\text{max}}$, laser-to-proton conversion efficiency $\eta_{\text{laser-proton}}$, and Cu Kα yield on $I_{LP}$ (TW/cm²).
- Different samples (Al/Cu/CH and Cu[ref]) are compared across the graphs.
- Additional materials (HOPG1, HOPG2) are also considered in one of the graphs.
Absorption physics is complex because of two regions with density gradients. Absorption is sensitive to details of the plasma surface.
Simulations with 2D OSIRIS – by Roger Evans

Enhanced energy coupling to electrons and changes to the electron spectrum are predicted.

Peak at same S.L. as observed experimentally.

Increasing density gradient.

Number of electrons (arb. units)

0 TW/cm²

1.8 TW/cm²

11.7 TW/cm²

Total Beam Energy (arb. units)

Energy (MeV)

Long Pulse Intensity (TW/cm²)

0 TW/cm²

1.8 TW/cm²

11.7 TW/cm²

0 1 2 3 4 5

0 10⁴ 10⁵

0 10³

0 2 4 6 8 10 12

0 2 4 6 8 10 12 x 10⁶

200fs

300fs
1. Absorption sensitive to details of the plasma surface

2. Volume heating when enough underdense plasma

E. Lefebvre et al, PRE 55,1011 (1997)
Nonlinear electron heating in ultrahigh-intensity-laser plasma interaction
Transition from tight focus to 1D geometry

Defocus scan

Laser intensity (W/cm²)

Maximum proton energy (MeV)

Energy scan

Tight focus: large divergence

1D geometry
Effects of refluxing/recirculating electrons

(1) Reheating due to refluxing?

A similar effect observed previously with 5 µm-thick targets

\[ \phi_L \gg L \]

Refluxing could account for better energy coupling in thin targets

\[ \phi_L = 160 \mu m \text{ for } 10^{18} \text{ W/cm}^2 \]

But here the target is thick!

\[ \phi_L \sim L \]

Refluxing does not explain the observed enhancements

(2) Increase in acceleration time?

Laterally spreading electrons take longer to ‘escape’ the sheath

\[ \text{Escape} = \frac{150 \mu m}{c} = 450 \text{ fs} \]
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Lateral fast electron transport in thin foils

Motivation:
- Fast electron guiding along cone walls
- Important for the optimisation of TNSA ions

Lateral transport can arise due to:
1. fields confine electrons in a potential well along the surface
2. hot electron refluxing within target

Previous study:
- McKenna et al, Phys Rev Lett (2007)

Transverse refluxing of fast electrons

Rear

Edge

![Graphs showing maximum proton energy and conversion efficiency vs. target surface area for Rear and Edge configurations.](image)
Shaped targets for ‘shaped’ proton beam
Contributors

D. C. Carroll, R. Gray, O. Tresca, X. H. Yuan, M. N. Quinn, M. Coury & P. McKenna
*SUPA Department of Physics, University of Strathclyde, UK

Central Laser Facility, STFC Rutherford Appleton Laboratory, UK

M. Burza & C.-G. Wahlström
Department of Physics, Lund University, Sweden

R.G. Evans
Department of Physics, Imperial College London, UK

X.X. Lin & Y.T. Li
Institute of Physics, Chinese Academy of Sciences, Beijing, China
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SUSSP68 International Summer School
& NATO Advanced Study Institute
Laser-Plasma Interactions and Applications
14th - 27th August 2011

Deadline for bursary applications has passed (28 February 2011)
Applications process remains open for self-financing students
http://sussp68.phys.strath.ac.uk
Thank you for your attention!
Distinguished lecturers and guest speakers:

Introduction to laser-plasma interactions: Prof. B. Bingham
The theory of laser-plasma interactions: Prof. A. A. Andreev & Prof. L. Silva
Plasma wave electron acceleration: Prof. V. Malka & Prof. G. Shvets
Undulator and betatron photon sources: Prof. D. A. Jaroszynski
High harmonic generation: Prof. M. Zepf
Ion acceleration: Prof. M. Roth & Dr. P. McKenna
Shock waves and equation of state: Prof. S. Eliezer
Inertial Confinement Fusion: Prof. M. Rosen & Prof. W. Kruer
Fast Ignition & implosion hydrodynamics: Prof. S. Atzeni & Dr. J. Pasley
Modelling techniques and simulations: Dr. A. P. L. Robinson
Materials at high energy density: Prof. S. Rose
Applications, diagnostics and targetry: Prof. D. Neely & Mr. M. Tolley
High power laser projects: Prof. J. Collier & Dr. T. Goldsack
Public lecture: Prospects for IFE: Prof. M. Dunne
Dissemination:
Lecture notes will be published as a textbook

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