Short pulse laser driven relativistic electron transport in wire targets

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ABSTRACT

• We study the interaction of short pulse lasers with the ends of copper wire targets capped with nail-heads.

• Beams from $1.7 \times 10^{20}$ W/cm² intensity are propagated to critical, where they generate Mev particle-electrons that transport down the wires, drawing resistive cold-fluid return-currents.

• We model this phenomenology with the new implicit/hybrid code e-PLAS.
We look at “nail-like” systems with the laser striking the “head”.

At the Philadelphia APS we showed that our methods reproduce Kodama’s cone-wire results, and studied recent RAL-like nail-head experiments.

Here we look at the basic elements responsible for wire heating.

Scale measure: typically 250 µm in our simulations
We use the RAC e-PLAS code

Features:
2-D, Implicit Moment E & B-fields, PIC hot electrons, fluid background electrons and ions, relativistic corrections, electron scatter and drag off ions, background (cold) electron resistivity, laser light propagation to hot emission at critical surface, ponderomotive effects, cartesian (x,y) or cylindrical (r,z) geometry.

Special Capabilities:
• High target densities (>10^{25} e-/cm^3), vacuum regions,
• No Δt restraint from \( \omega_p \Delta t < 1 \), global problems
• Particle instabilities
Classical collisional treatment includes:

- Scatter done at the Spitzer rate, but modified for metals by a floor (at typically 100 eV) on the background temps.

- Hot electron scatter and drag rates relativistically corrected to match Jackson’s and Mosher’s analysis.

- Heated cold e⁻ (from the hot drag and cold scatter) coupled to the ions at a Spitzer rate. We often find that $\nu_{c-i} \sim \nu_{h-c}$ — then cold heating is directly mirrored in the ions.
A traditional ICF light deposition package is used for efficient laser-interaction studies

- Grid-following - no need for an extra-fine mesh to propagate light waves. *Density limited* PMF.

- Dump-all, inverse-bremsstrahlung, and anomalous absorption.

- PIC hot electrons emitted in a relativistic Maxwellian or shell momentum distribution, isotropic or in a beam.
First we look at e-PLAS predictions for a thick (40 \( \mu m \) diameter) copper wire (Z = 15).

- 30 \( \mu m \) spot, t=940 fs
- Hot e- density trapped near spot
- Filamentary break-up
- 10-fold decay over 100 \( \mu m \)
- 2 keV peak in head
The self-consistent B- and E-fields trap and retard the hot e⁻ transport.
Flux and phase plots document the trapping

- **t=940 fs**
- **Circulating hot e⁻**
- **Returning colds**
- **Reduced hot e⁻ flux with penetration**
- **Trapping near critical**
We examine the contributing physics elements by reduction to a model problem

• The laser spot gets a flattened intensity profile to move B-field sources to the spot edges.

• The hot emission is directed in a 1º beam into the wire with a mono-speed @ γ energy to help track beam deflection mechanisms.

• Hot e⁻ drag, cold e⁻ scattering, and the B-field are turned “on” and “off” to isolate transport inhibition mechanisms.
Hot e- penetration increases as physics elements are reduced; at t = 940 fs we see:

- **all “on”**
- **B=α=0, ν “on”**
- **B=α=ν = 0**

- Surface trapping (reduced by drag)
- Directed beam
- E-field retardation
The hot $e^-$ phase space captures the effects of the B-field and cold-scattering collisions

- **all “on”**
- **$B=\alpha=0, \nu “on”$**
- **$B=\alpha=\nu = 0$**

- **hot $e^-$ captured by B-field**
- **$e^-$ beam slowed in resistive E-field drawing the return current**
- **free $e^-$ beam reflected at wire back side**
The collisions and B-field affect the background heating

- **all “on”**
  - Background heating
  - Surprisingly high temps from a tight spot (B=0)

- **B=α=0, ν “on”**
  - No resistivity
  - No heating

- **B=α=ν = 0**
  - Cold Temp
Conclusions

• Application of e-PLAS to copper wires shows surface trapping of the hot electrons.

• Model problem studies that B-fields trap hot e\(^{-}\) near the laser spot. This is consistent with earlier implicit foil simulations.

• Wire heating derives principally from resistive scattering of the return-current cold electrons, with some addition from hot e\(^{-}\) drag.

• Optimal heating expected from a tight, flat spot minimizing B-field trapping.