Electron Transport Experiments & Model

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Nail wire targets designed for benchmarking

Rationale:
- Simple - no glue, simple geometry
  - Large head so laser can reliably hit it
- Accessible to diagnostics
- Small - completely simulate

Status:
- Tests at RAL show overall transport
  - More detailed diagnostics at Titan (this week)
- First simulation results show differences

100 \( \mu \)m dia head
20 \( \mu \)m dia wire
1 mm to bend
Cone-wire energy deposition is hard to model

- Cone has complex structure

- Laser interaction very sensitive to aiming?

XUV - 256 eV
Laser plasma interaction simpler in nail target

- 100 micron head is easier to hit
- Interaction surface is flat
- Focus spot is visible

It is convenient that the nail edges are highlighted.
Wire allows access to many diagnostics

- Did we have pinhole cameras that could see the top of the nail head and locate where the laser hit??

Reflecting Parabola

Incoming Laser

Target

K_α - 8.03 keV

12°

43°

backlight

XUV-256&68 ev

HOPG spectrometer
Diagnostics show details of transport in wire

• Return current heating - xuv
• Energetic electron current - $K_{\alpha}$
• Surface heating - xuv
• Hydro expansion - backlight

• At Titan will add
• Surface vs Bulk current - Ti coated (Green et al expansion data suggested that heating was on surface)
• Laser directly on wire head
• External fields - (can’t field that til next year.)
68 eV image shows expansion

- Hydro jets at every inside edge
- Irregularities in expansion along wire
- Low level heating for entire length of wire
- Hotter for ~100 µm - associated with hot electrons and a surface
256 eV shows state at shorter time

- Can see through low density blow-off
- Limb brightening outlines wire
  - About 0.04 \( \mu \text{m} \) of Cu expanded a bit
- Surface current \(~300\ \mu\text{ms}\)
  - Similar to \( K_\alpha \) prop length
- Laser off center on head
$K_\alpha$ shows propagation of high energy electrons

- Electrons have limited range
  - Decay slope $\sim 220 \, \mu m$
- Surface current??
Current propagation different in nail target

- **Cone-wire emission**
  - seen from the whole length (~1 mm)
  - peak at the end of the wire (e⁻ refluxing?)

- **Nail target emission**
  - decays exponentially. (1/e ~ 100 µm)
We aim to accurately model this experiment

That means properly describing the experiment as well as properly simulating the physics

- Target geometry
- Laser pulse - including prepulse
- Properly generate current
- Analyze in terms of diagnostics
Laser prepulse will modify initial state

- Prepulse causes substantial deformation
  - RAL prepulse varied, guessed at $10^{14}$ W/cm² for 400 ps
  - Titan prepulse is measured on each shot

Density contours, g/cc

We must know initial geometry
### Simulations take different approaches

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Hot electron propagation patterns

**Energy Density**

- Energy density
- Electron: t=825fs
- Ion: t=825fs
- 100 keV, 10 keV, 1 keV, 100 eV, 10 eV

**PICLS**

Energy localization inside the nail head.

**e-PLAS**

Most of hot electrons remained in the nail head (peak density: 2e22 cm\(^{-3}\)).

Exponentially decay to 1e20 cm\(^{-3}\) from x=90 to 260 µm.

Some surface current flow along the wire surface.

**2D LSP**

Target: Cu\(^{15+}\) with initial \(T_e\)@ 10 eV

- t=1ps
- t=5ps (maximum temperature)

Energy localization inside the nail head.

**STRONG SURFACE CURRENT ALONG THE WIRE.**

Hot electrons mainly propagating along the axis.

Some currents flow along the wire surface.
Heating of the nail target - above keV electron temperature

**PICLS**

Energy Density at t=2ps

- 1 keV
- 500 eV
- 5 keV
- 100 keV

**Range:** 0.05 - 500 keV\(\times(n/n_0)\) 0.05 - 50 keV\(\times(n/n_0)\)

**e-PLAS**

607 fs

- **Temp**
- **Cold Temp**

**T_e max:** 3 keV

**T_e >100 keV in the head!**

Strong Joule heating by surface current \((T_e \sim T_i > 500 \text{ eV})\)
Heating of the nail target (continued)
-- Radiative cooling is important

2D LSP

1D HYADES simulation show that plasma quickly cools down to around 400 eV in less than 1 ps due to radiative cooling.

In LSP, Initial ionization charge state has a big effect on the background plasma heating.

Inline average atom LTE opacities;
100 radiation groups from 50eV to 40keV (log distribution);
SESAME 114 EOS. Hydro is ON.
Strong surface E&M fields in all simulations - diagnostics will be fielded in future to confirm their presence.

PICLS

Range: $\pm$ 10MG

e-PLAS

300 MG fields cover the wire surface and the nail head

E-field is 2 MV/µm
Strong surface E&M fields in all simulations - diagnostics will be fielded in future to confirm their presence

Strong surface magnetic fields, 100 MG - similar to e-PLAS simulation

Net current (~ 400 kA) about 3x of Alfven current

$E_r$ at t=0.5 ps

$E_r \sim 2$ MV/µm, similar to e-PLAS simulation
Modeling status and future work

• **Similarities**
  - Energy localization near the nail head
  - Strong surface fields

• **Differences**
  - Strong surface current for PICLS, compared to e-PLAS and LSP

• **Problem**
  - Unrealistic temperatures

- Closer approach to parameters used in the experiments
  — preformed plasma due to pre-pulse
  — target dimensions, density
  — similar laser specifications

- Check electron scattering functions

- Analyze output in terms of comparable to experimental diagnostics
Experiments and Models are converging

• Initial nail experiments show electron propagation
  – No long range energetic electrons visible
  – Surface heating visible with ~ range of energetic electrons
  – Hydro jets appear at all inside angles, irregular heating
  – Results substantially different from cone wire configuration
  – More detailed measurements to come on Titan

• Will end with understanding of differences between simulations and experiment??