High Energy Electron Transport in Solids


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High Energy Electron Transport in Solids

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This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under contract W-7405-Eng-48.
1) Drive lasers compress the fuel

2) A Petawatt laser generates energetic (MeV) electrons

3) The electrons transport the ignition energy to the core
Experiments are approaching huge currents required

- Igniting 200 g/cc DT to 10 keV
- Requires 40KJ -> $2e^{17} \text{ e}^{-} @1 \text{ MeV}$
  \[ \Rightarrow 200 \text{ MA, 15 ps} \]

- Energy conversion ~ 30% demonstrated

- With laser energy up to 300 J
  \[ \Rightarrow 10-20 \text{ MA, 1 ps in our targets} \]
We use room temp metal to stand in for DT plasma

• **Cu-K\textsubscript{α} fluorescence shows electron propagation**
  – A Bragg mirror images the fluorescence emission
  – Observe propagation in slab and wire geometries

• **Basic findings**
  – e\textsuperscript{-} spread is independent of energy
  – Energy deposition is proportional to energy
  – Propagation length is approx the same in all
  – Largest deposited energy requires corrections
    – Temperature reduces mirror efficiency
    – Resistance is limiting current
  – Indications of surface bottleneck?

• **Have developed new diagnostics to show local temperature, starting to give a handle on details.**
We use $K_\alpha$ imaging to see electron transport in Al

- With Cu-$K_\alpha$ (8 keV) can see $\sim$ 100 $\mu$m into Al
- Use three geometries
  - **Buried layer**: cross section of prop in Al/Cu/Al
  - **Alloy**: Side view of prop thru Al:Cu
  - **Wire**: transport confined to Cu wire
Electron beam spread in Aluminum is independent of energy (30J, 70J, and 300J)

RAL data
30J, 70J, 300J, 0.8 ps
Cone angle 40°
Min diameter 80 µm

Note initial spread -- starting spot size is ~ 5X laser spot size

Spread well described by heuristic Monte-Carlo model

• $e^-$ generation efficiency & energy from local intensity (Beg scaling)
• Random transverse momentum independent of location
⇒ High energy $e^-$ are forward directed, low energy $e^-$ spread out
Fluorescence $\propto$ Laser energy and Cu fraction

Fluorescence gets more complicated for high pulse energy

MC model

Except for PW shot onto thin target
Current seems to drop quickly near front surface.

These are 70 J shots for which temp corrections aren’t needed.
Side view of CuAl gives the same result - spreading at entry surface and ~ 70 µm mfp

1/e decay length
~ 70 µm
And in Cu wires where the current can’t spread

Normalized current density and mfp are similar to slab geometry

Cross section is much smaller, so total energy into wire is ~ 2% of beam energy
With increasing current we are getting into complications

• Reached current densities that require more sophisticated diagnostic
  – Must account for temperature
  – Resistance limitations become important

• Challenge is in understanding the laser-plasma interface region
Have added HOPG spectrometers for better understanding of temperature gradients

- 0.5 µm Al/5 µm Cu target
- 500 µm x 500 µm size
- 0.5 ps, 300J irradiation

Peak temp 2x general temp
-> strong heating from initial beam

3:1 front:back intensity ratio in He\textsubscript{α}
-> strong axial temp gradient
-> front surface ~ 2 keV

Cu K shell spectrum

256 eV XUV image
Fluorescence collection efficiency decreases with temperature.

Bragg mirror collection energy 100

Intensity

Photon Energy, eV

Temperature, eV

Fraction of Kα collected

Kα detection efficiency
Resistivity limits propagation at high current density

Temperature (eV) vs. Resistivity (Ohm m)

- Ohmic limit in FI
- Current (foil) experiments

Materials and densities:
- Au
- Al
- CD 1 g/cc
- D2 1 g/cc
- CD 10 g/cc
- D2 10 g/cc
- CD 100 g/cc
- D2 100 g/cc

FI imploded fuel

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Higher current would cause stronger limitations.

Current into the wire was limited so fields aren’t too bad.
Summary

- Currents are still scaling with increasing intensity
- Propagation lengths are appropriate - ~ 100 μm
- Reached current densities that require more sophisticated diagnostic
  - HOPG spectrometers for current and temperature
- Resistivity may be limiting wire current
- Challenge is in understanding the laser-plasma interface region
  - Created diagnostics and analyses to probe that area
  - Adding packages to LSP for self-consistent electron creation in plasma