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Visible/UV Spectroscopic Analysis of Plasma Generation from Fine Wires

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Abstract

Experiments are underway to study plasma generation from fine wires. For these experiments, a capacitive discharge (100kV, 80kA) drives one or more aluminum wires (25-100 microns) to form a plasma. Visible/UV spectroscopic diagnostics are employed to obtain spatial and temporal temperature and density profiles. Experiments are conducted in a return current geometry to study the effects of global, as well as self-magnetic fields, on plasma production. Results are compared to 1-D MHD calculations and scaling laws for plasma mass ablation rates. The goal of this research is to generate a quiescent, highly ionized, unmagnetized plasma in the 10^{15}-10^{17} cm^{-3} regime, with a temperature of 1-10's of eV for a few hundred nanoseconds. Such a plasma could be used in electron beam accelerators to aid in beam focusing, an important factor in applications such as flash x-ray radiography[1].

1. D.R. Welch, et al., "Transport of a Relativistic Electron Beam in Gas and Plasma-Filled Focusing Cells for X-ray Radiography," Phys. Plasmas, Vol. 11, No. 2, pp. 751-760, 2004.

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Outline

- Electron Beam Diodes used for Flash X-ray Radiography
- Proposed Wire Ablation Plasma Source
- Experimental Test Configuration
- Wire Images/Expansion Rates
- Wire Heating and Plasma Breakdown
- Spectroscopic Results
- Summary and Conclusions
- Future Work

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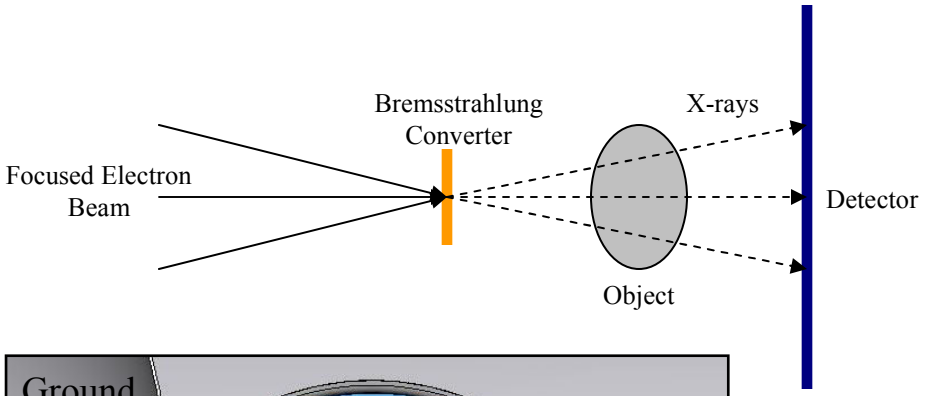
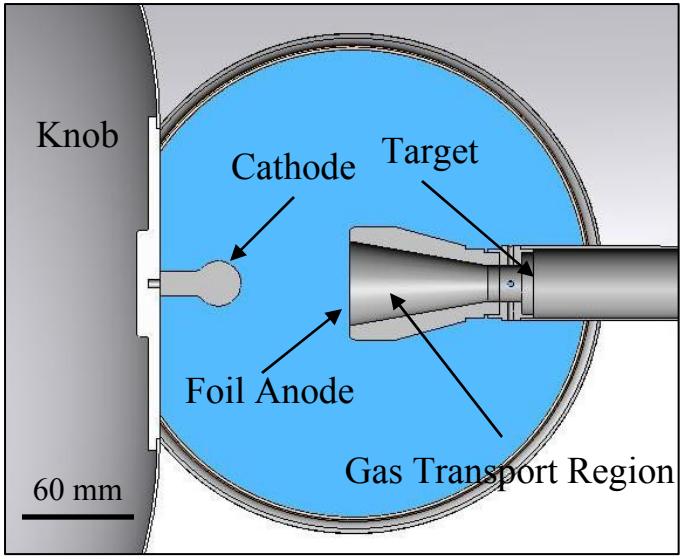
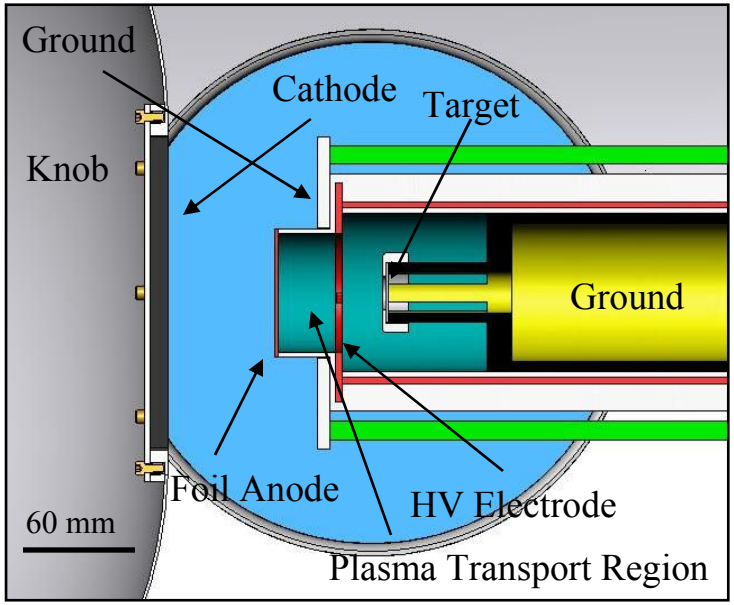
Electron Beam Diode Configurations used for Flash X-ray Radiography

Neutral gas (air) and pre-ionized plasma (hydrogen) diode configurations are being investigated for use as point-projection radiographic sources.





Standard Paraxial Diode



Plasma-Filled Paraxial Diode

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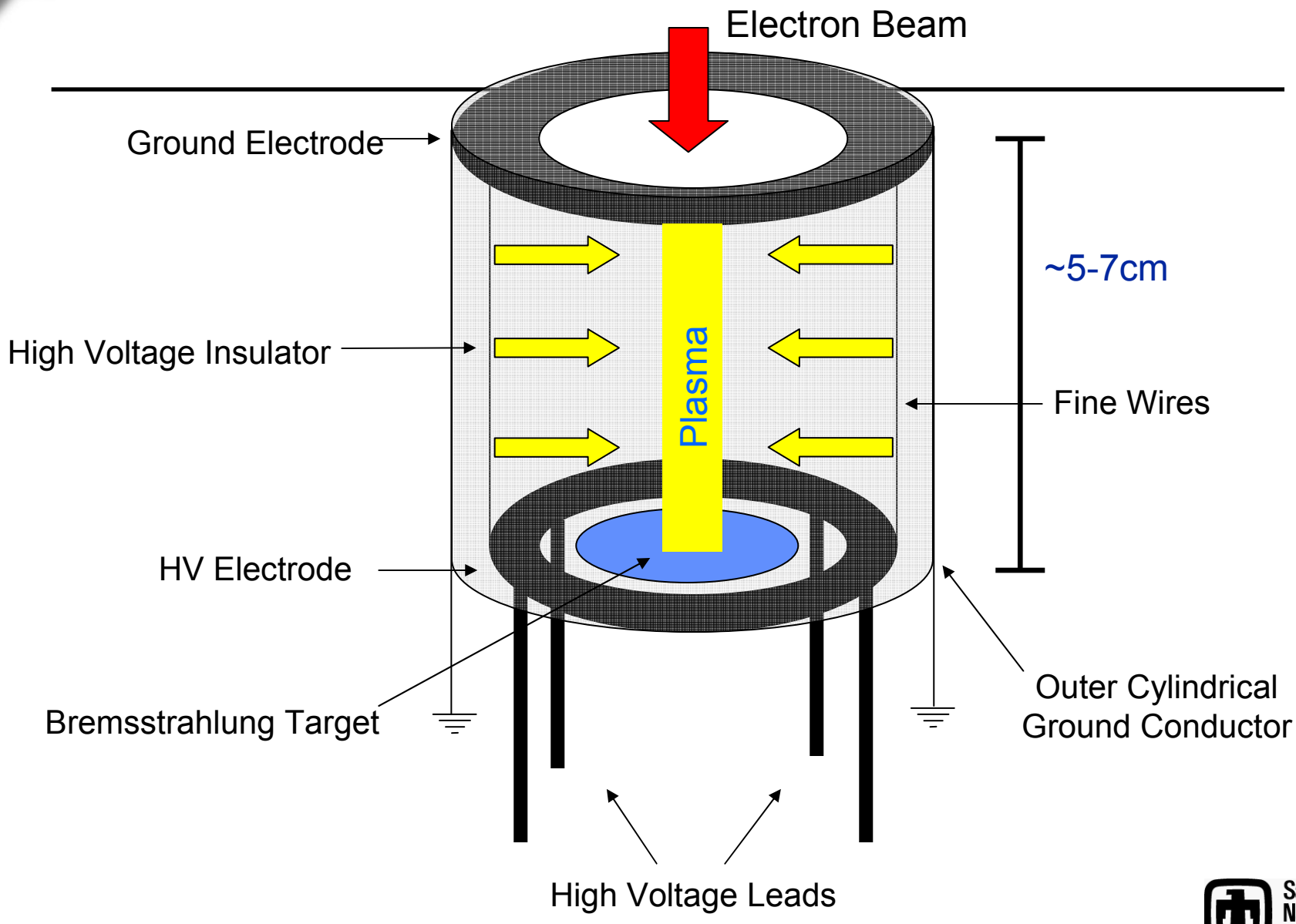
Conceptual Drawing of Wire Ablation Plasma Source for Plasma-Filled E-Beam Diode



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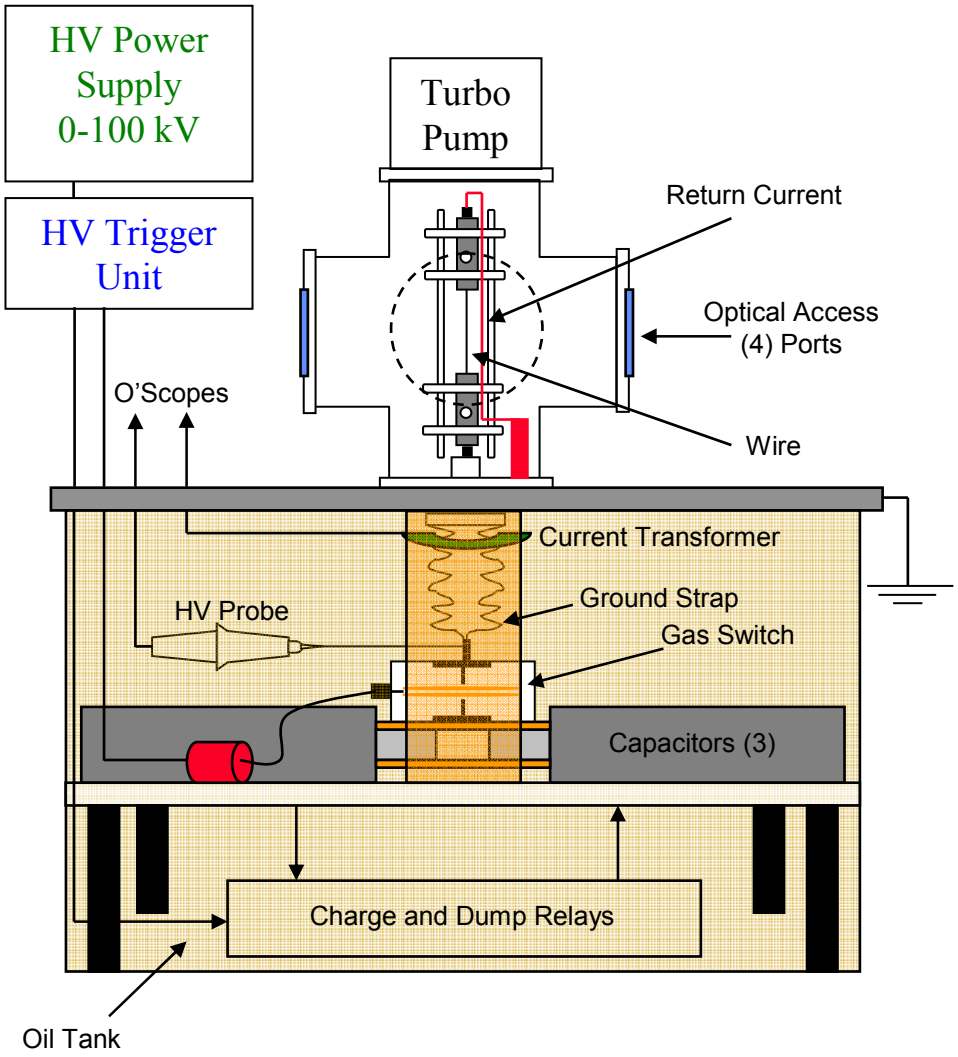
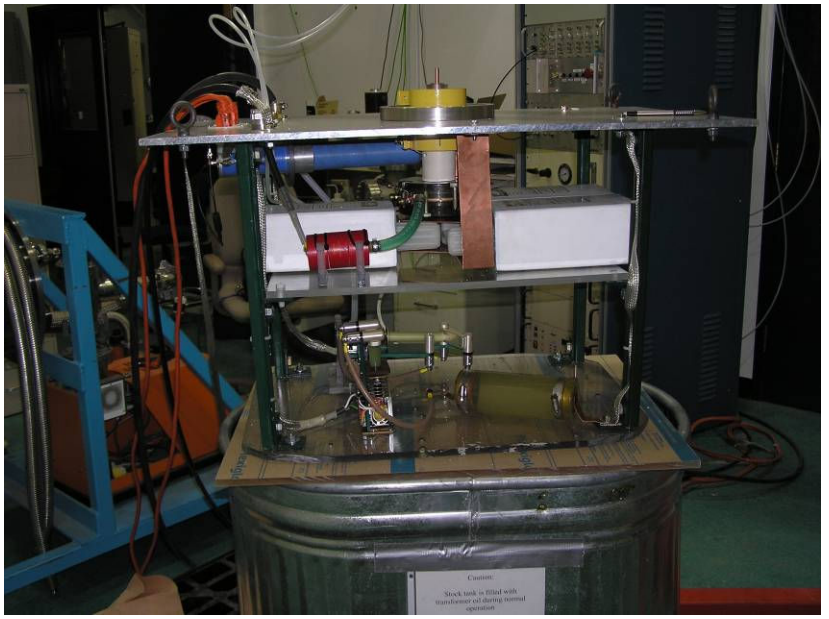
Experimental Test Circuit





- **Glassman 100kV Charging Supply**
- **Maxwell 50kV Trigger Amplifier**
- **General Atomics 110kV, 80nF Capacitors (3)**
- **Maxwell Model 40264 HV Spark-Gap Switch**

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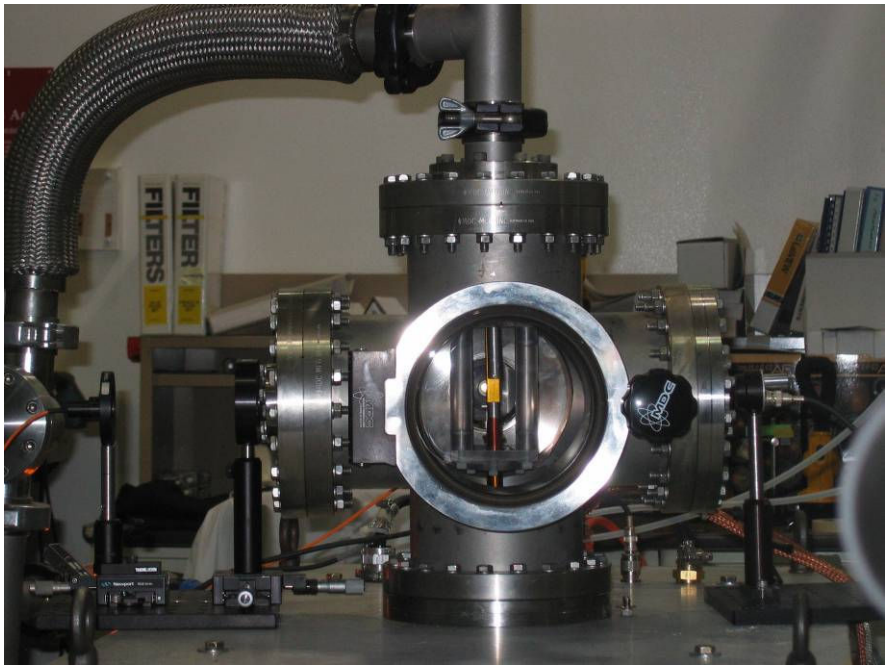
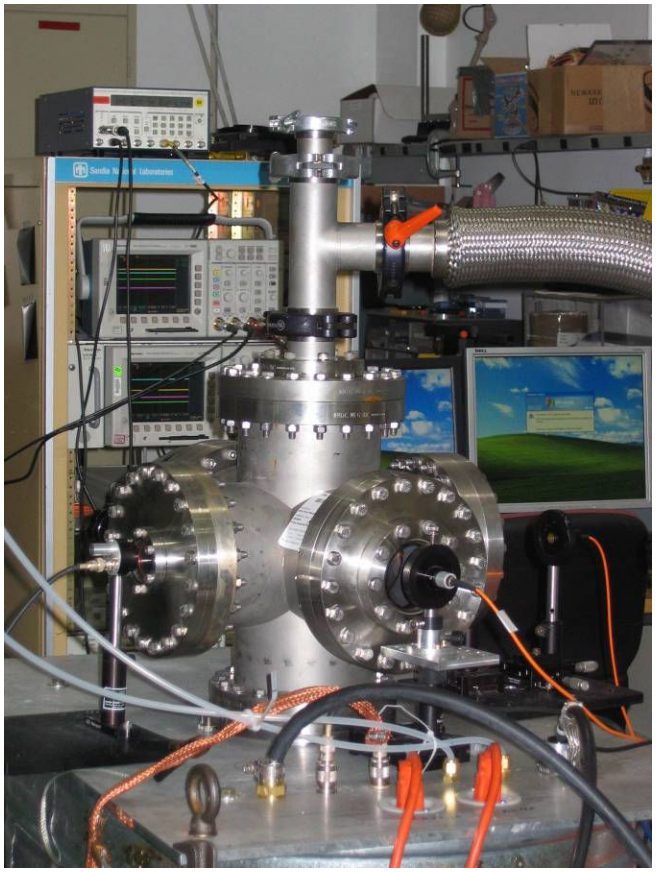
Experimental Test Chamber





- 8 Inch, Six-way Cross, Turbo-Pumped Vacuum Chamber
- Wire Holder Assembly with Return Current Plate
- 4 View-port Optical Access

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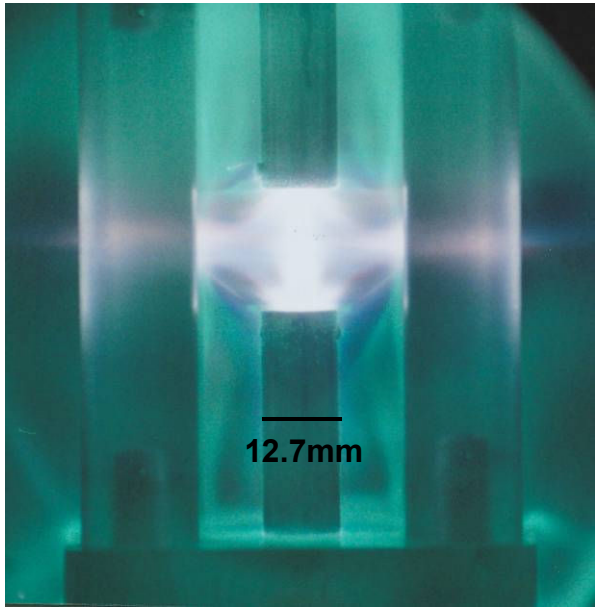
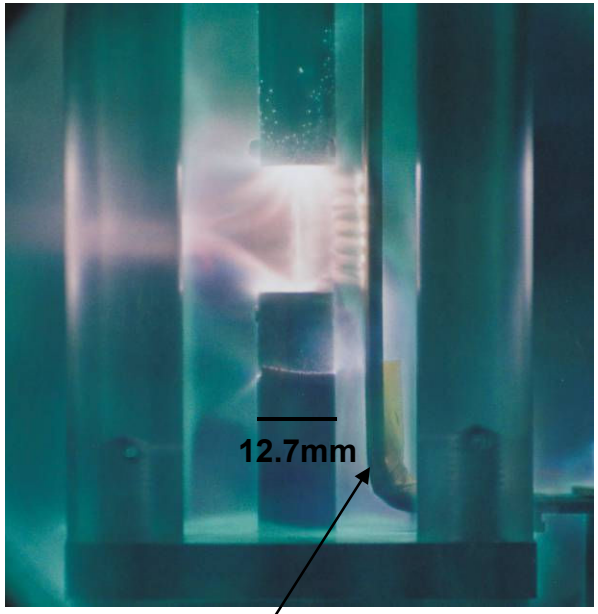
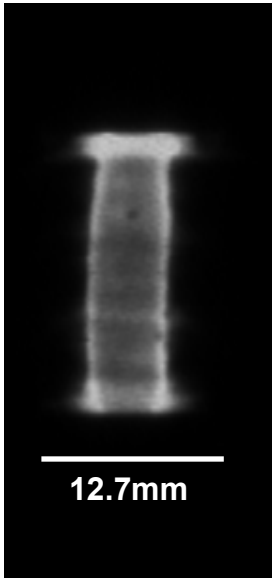
100μm Aluminum Wire Ablation Images



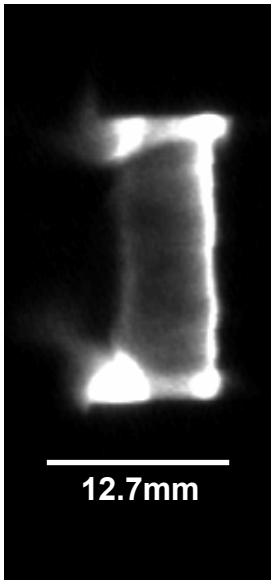
No Current Return



Current Return



Without Return Current



With Return Current

JxB

Open Shutter Visible Light Image of 100μm Aluminum Single Wire with and without current return

3ns Gated ICCD Image of 100μm Aluminum Single wire with and without current return

(600ns into current pulse)

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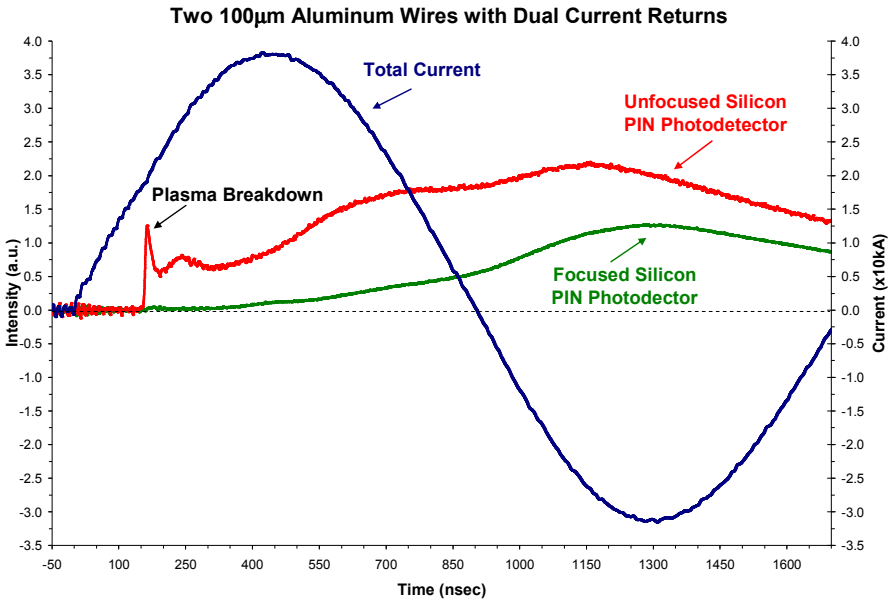
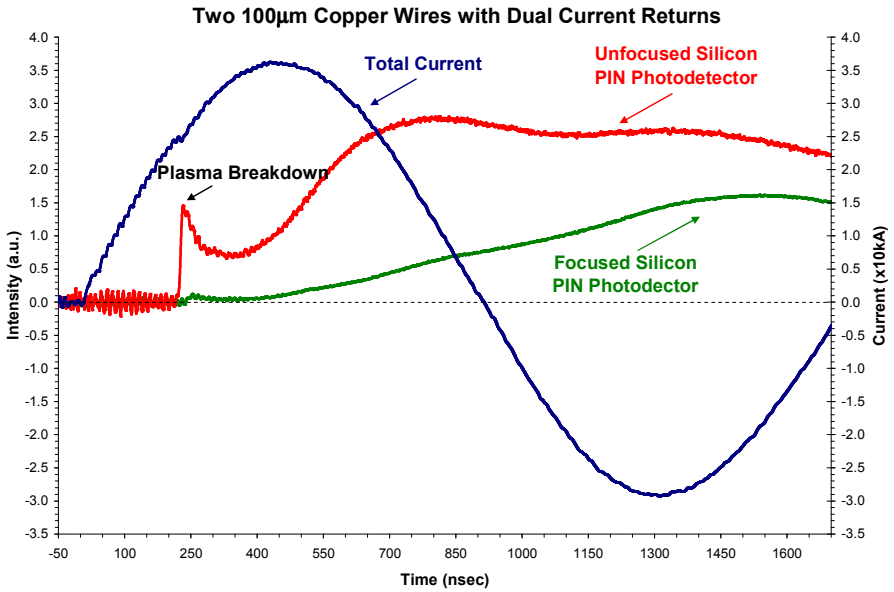
Visible Light Emission from Two 100μm Wires with Dual Current Returns





Aluminum

- Electrical resistivity: 2.67μΩ-cm
- Melting point: 660°C
- Boiling point: 2519°C
- Density: 2.70g/cm^3

Copper

- Electrical resistivity: 1.67μΩ-cm
- Melting point: 1083°C
- Boiling point: 2562°C
- Density: 8.94g/cm^3

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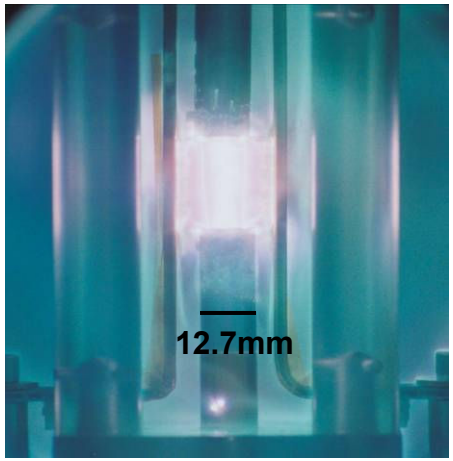
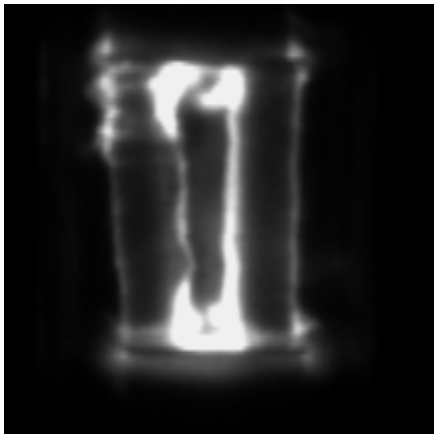
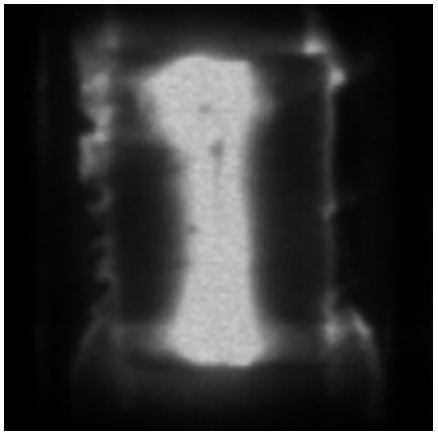
Plasma Ablation from Two 100μm Aluminum Wires with Dual Return Currents



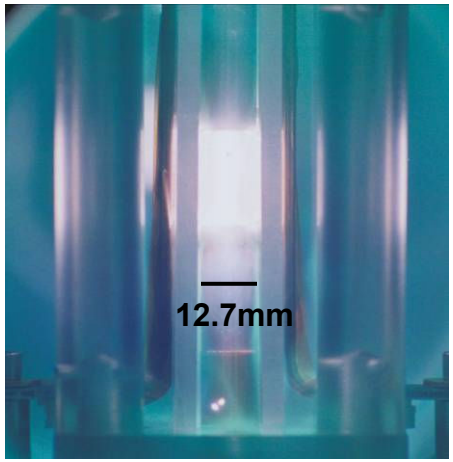
Two wires without Insulators



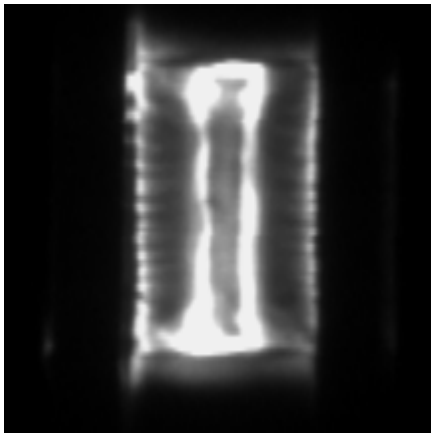
620ns



830ns



Two wires with Insulators



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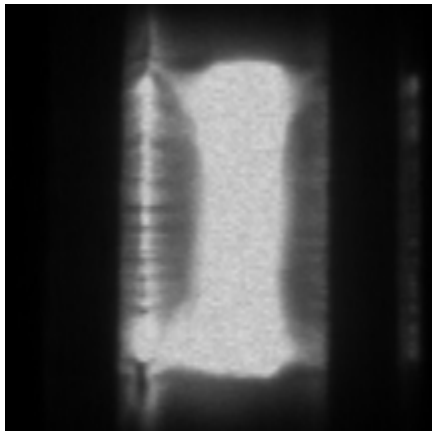

830ns

0.25mm - 1.0mm Striations Observed on Insulator Positioned 1mm from Wire

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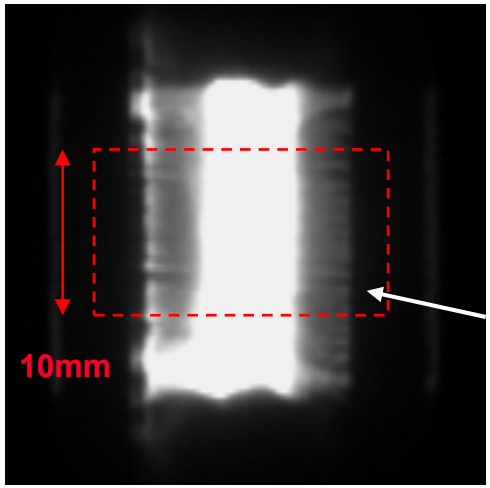
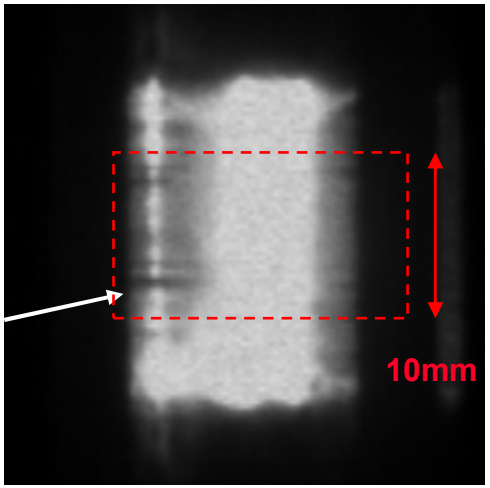
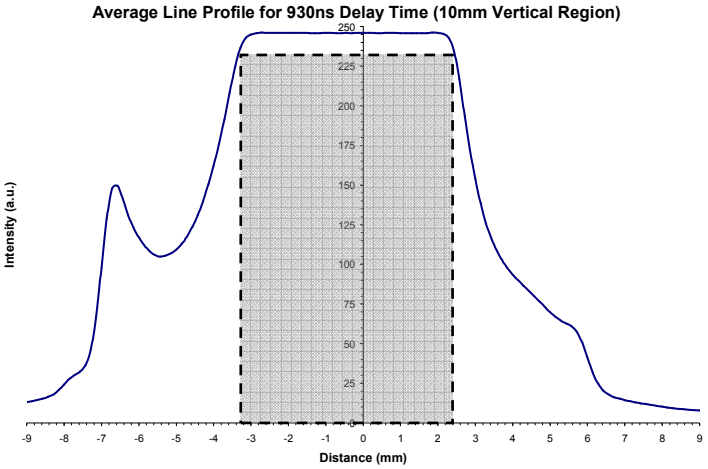
Plasma Ablation from Two 100μm Copper Wires with Dual Return Currents



Dielectric Insulator

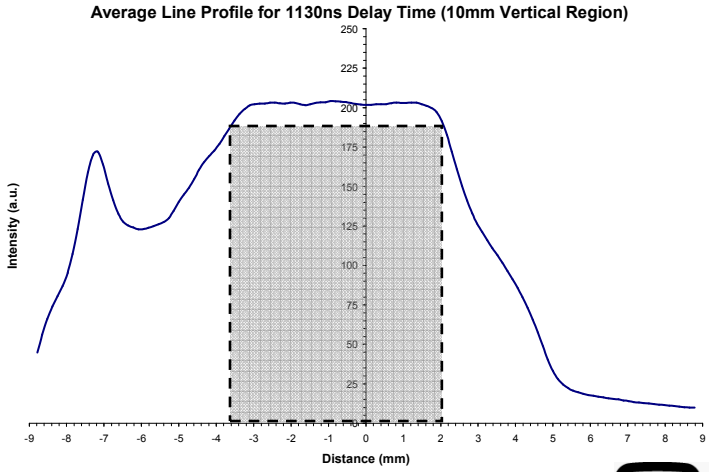


920ns



5.8mm Distance

1130ns



5.8mm Distance

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Resistive Heating and Plasma Breakdown Times for 100μm Aluminum and Copper Wires

Wire Configuration	Peak Current (kA)	Current Rise-Time (ns)	Resistive Heating (ns)
Single Al Wire no return	33.5	495	125
Single Al Wire with return current	35.5	480	119
Two Al wires with single current return	35.6	475	175
Two Al wires with two current returns	38.0	440	162
Two Cu wires with two current returns	36.2	435	220

Time-Dependent CR Modeling of Wire Ablation Plasma Source

- Time dependent collisional-radiative modeling of plasma parameters throughout the current pulse.
- Self-consistent calculations of line shapes, including Stark, Doppler, and opacity effects.
- Determinations of electron densities, percent ionizations, intensities, and opacities.
- Hydrogen Balmer line shape calculations include quasistatic ion, electron impact, and ion dynamic effects.

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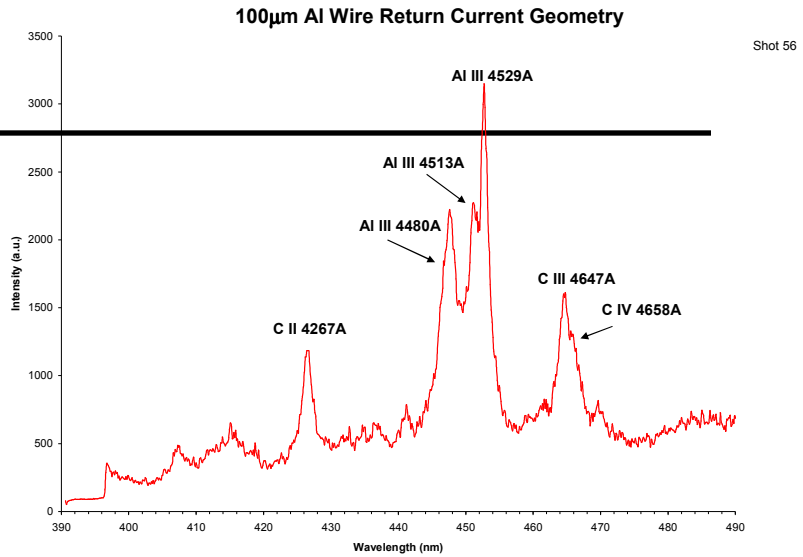
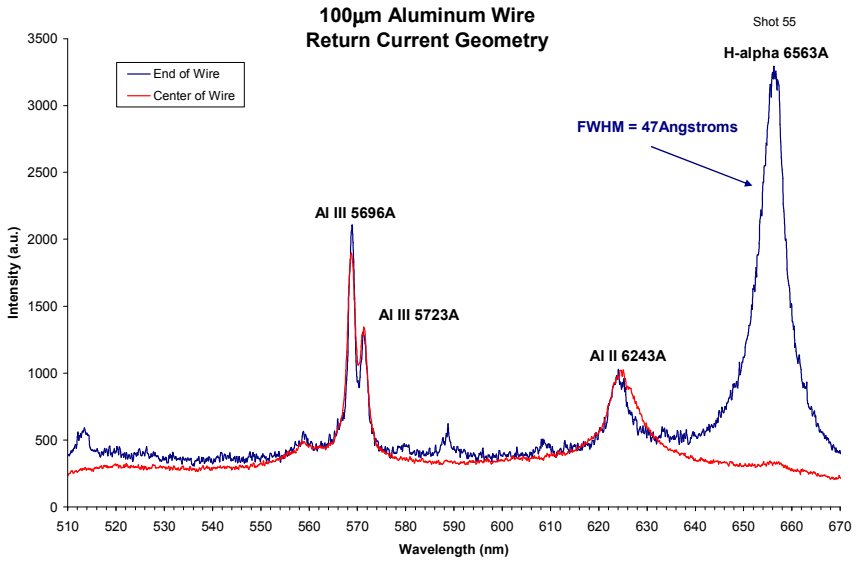
Spectroscopic Analysis

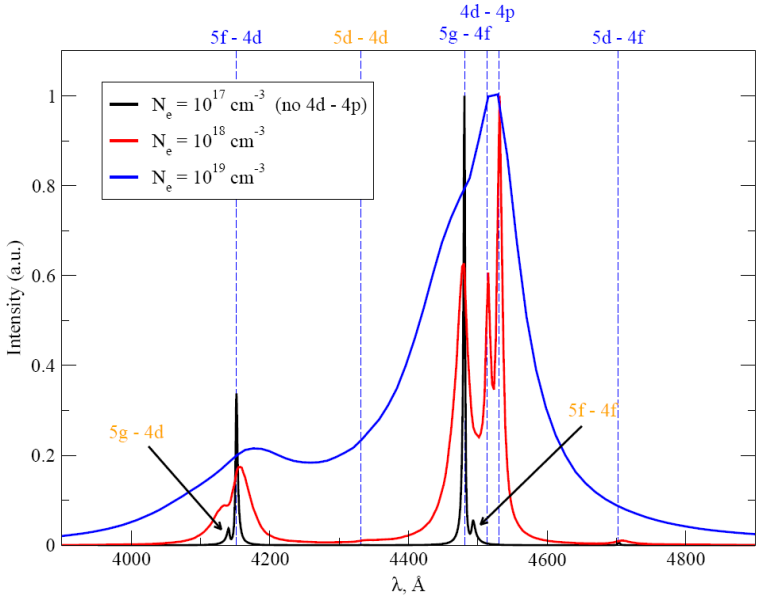
- Line shapes (Stark Broadened) give plasma electron density (N_e)
- Line ratios give electron temperature (T_e)
- Absolute line intensities give ion densities (N_i)
- Absolute continuum intensity gives electron density (N_e)



Al III; T = 4 eV



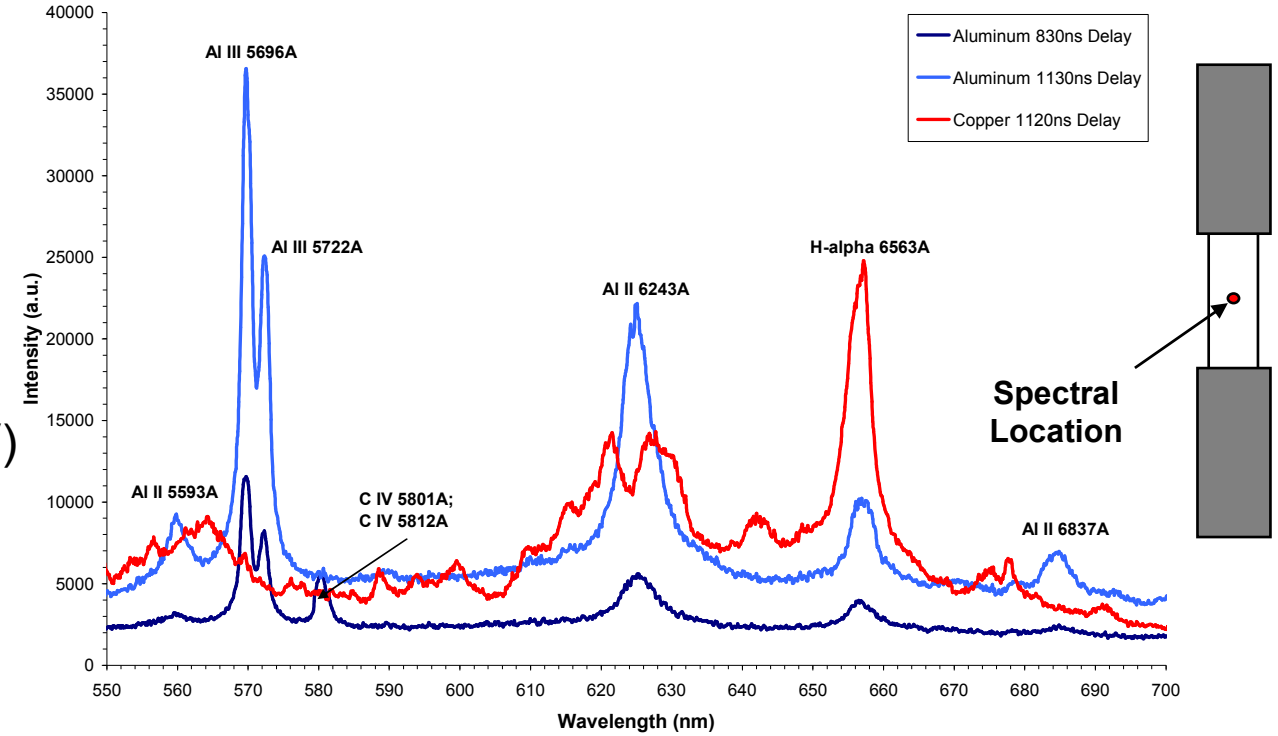
Calculated Electron Density (N_e): $1x10^{18}$ cm^{-3}



Calculated Al III Lineshapes

Spectra from 100μm Aluminum and Copper Wires with Dual Return Currents

- Spectra is taken mid-way between wires and electrodes.
- Observation of carbon, hydrogen, and metal ion species.
- Higher charge states (C IV) observed earlier in time.
- Increased line/continuum intensity with time.



*Experiments are underway to measure carbon charge states in the ultraviolet (2000-3000 Angstroms) region.

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Conclusions

- Commenced studies investigating the feasibility of developing a wire ablation plasma source suitable for incorporation into electron beam diodes used for flash x-ray radiography.
- Investigated wire ablation from large (100μm) single and double wires with close return current geometries.
- Spectroscopically measured electron densities of $1x10^{18}$ cm^{-3} at a distance of 1.0mm from the wire core during peak current.

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Future Work

- Perform multi-wire linear and cylindrical array experiments in close return current geometries.
- Measure ablation plasma parameters (temperatures and densities).
- Demonstrate the ability to control ablation plasma parameters by varying current, geometry, and wire material.
- Add diagnostic capabilities including spatially varying multi-axis imaging, spectroscopy, and interferometry.

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