Quantitative Analysis of the Ablation of X-Pinches at 80 kA

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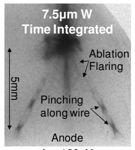
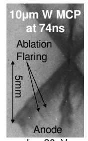
Introduction

In all exploding wire pulsed-power experiments, in which there is a dynamically significant global magnetic field, the plasma flow accelerated from the wires demonstrates a periodic density modulation. The process by which these modulations are driven require further experimental investigation to benchmark computational models and enable scaling to different systems. An X-pinch system, in which the ratio of global to local magnetic fields varies along the wire, offers an opportunity to examine this modulation in detail. In this work we investigate the wavelength of this ablation 'flare' structure as a function of atomic number, distance from the wire, time, and distance from the center of the pinch along the wire.



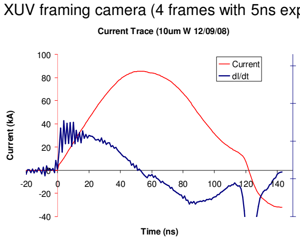


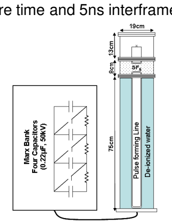
X-Pinch Pulser

- 80kA peak current with an ~40ns rise time (from 10-90%)
- 200kV Marx Voltage: 4x50kV capacitors @ .22µF each
- 1.5Ω pulse-forming line followed by self-breaking SF_6 switch

Diagnostics

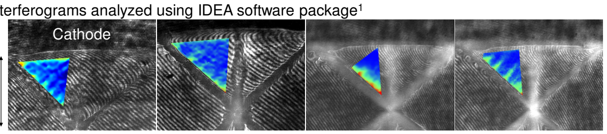
- Synchronized Mach-Zehnder interferometer & dark field Schlieren or
- Two frame Mach-Zehnder interferometer with a 20ns delay
- Gated XUV framing camera (4 frames with 5ns exposure time and 5ns interframe time)





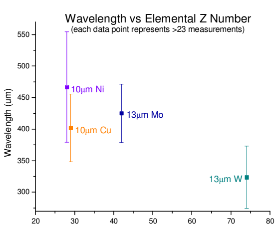
Ablation Wavelength as a Function of Material

Interferograms analyzed using IDEA software package[1]



10um W, 63ns | 13um Mo, 55ns | 10um Cu, 62ns | 10um Ni, 62ns

- The central column and coronal plasma expand more in lower Z materials creating less distinct flare and column structures, likely as a result of decreased radiative cooling.
- However, nickel (Z=28) exhibits well defined, flare structure and confined coronal plasma, whereas copper (Z=29) shows a much more diffuse structure.
- Shots demonstrate that the ablation flare wavelength generally increases with decreasing atomic number, as is observed in wire array z-pinches[2].



W λ=323.8 µm, σ=49.4 µm

Mo λ=425.1 µm, σ=46.5 µm

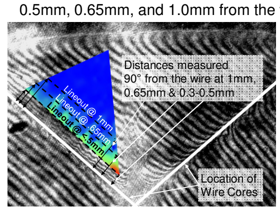
Cu λ=402.0 µm, σ=53.8 µm

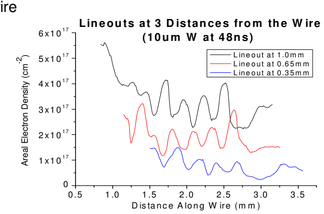
Ni λ=466.7 µm, σ=87.5 µm

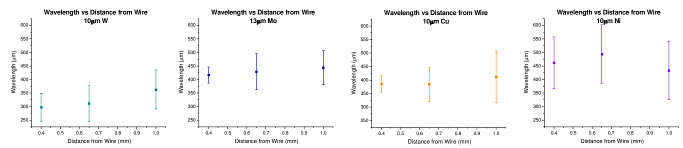
- The wavelength measured for W compares well to measurements taken in other exploding wire array experiments[2], and to recent 3D computational modelling[3].
- The large data set gives confidence to the measurements taken on three relatively unexamined wire materials.

Ablation Wavelength as a Function of Distance From the Wire

- Lineouts parallel to the wire are taken from unfolded interferograms at distances of 0.3-0.5mm, 0.65mm, and 1.0mm from the wire



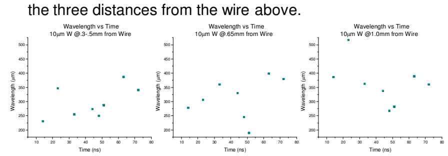




- In general the average wavelength increases with distance from the wire, as was recently observed in inverse wire array z-pinches[2].
- This effect is less distinct as atomic number decreases.
- Nickel does not follow this trend, and instead gets smaller as the distance from the wire increases. In wire arrays, nickel convects current away from the wire to a much greater extent than other materials[4]. This may cause the trend noticed here, as well as the more clearly defined flare structure as compared to copper.

Ablation Wavelength with Relation to the Current Peak

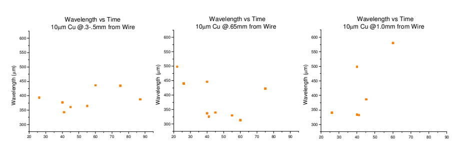
- To determine if there is a relationship between wavelength and time, the shots and lineouts are broken into pre-peak and post-peak categories (~48ns on this device), and averaged at the three distances from the wire above.



Average Pre-Peak
λ=277µm ± 43 at <0.5mm
λ=319µm ± 30 at 0.65mm
λ=401µm ± 69 at 1.0mm

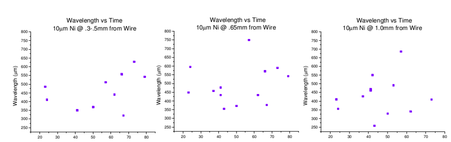
Average Post-Peak
λ=317µm ± 52 at <0.5mm
λ=304µm ± 88 at 0.65mm
λ=325µm ± 51 at 1.0mm

- The average wavelength of Tungsten appears to increase fairly rapidly as we move away from the wire in the first half of the current drive. However, in the second half of the current drive there is no conclusive evidence of increase or decrease in wavelength.



Average Pre-Peak
λ=369µm ± 19 at <0.5mm
λ=399µm ± 67 at 0.65mm
λ=379µm ± 63 at 1.0mm

Average Post-Peak
λ=406µm ± 31 at <0.5mm
λ=356µm ± 48 at 0.65mm
Insufficient data at 1.0mm

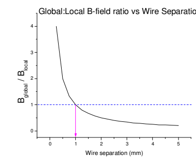


Average Pre-Peak
λ=416µm ± 55 at <0.5mm
λ=462µm ± 71 at 0.65mm
λ=420µm ± 84 at 1.0mm

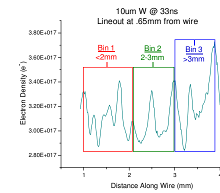
Average Post-Peak
λ=562µm ± 130 at <0.5mm
λ=607µm ± 153 at 0.65mm
λ=565µm ± 173 at 1.0mm

Ablation Wavelength as a Function of Distance Along the Wire

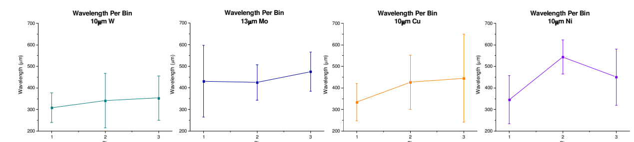
- A calculation of the B_{global}/B_{local} for a 2-wire X-pinch shows equal field strength when the wires are 1mm apart. Due to excessive plasma density close to the cross-point of the X-pinch, no data in the global field dominated region was collected. At distances greater than this the local field is dominant.



- In order to determine if the changing ratio between global magnetic field and local magnetic field strength plays any roll in the ablation wavelength, the data was broken up into 3 sections per material: <2mm, 2-3mm, and >3mm from the center of the X-pinch along the wire.

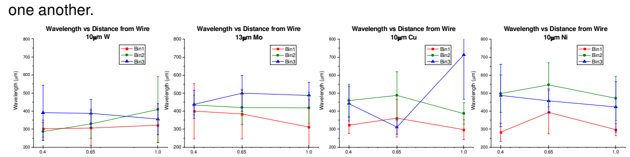


- Wavelengths that crossed significantly from one bin to the next were counted in the bin the greater fraction lay.
- Measurements within each bin were then averaged and plotted for each of the four materials investigated.



- W, Mo, and Cu showed an increase in wavelength along the wire, i.e. as B_{global}/B_{local} decreases from ~1 to ~0.25.
- Nickel does not demonstrate as clear a trend, however both bins at a lower B-field ratio show an increase over bin 1.

- The bin data was then broken into the three distances from the wire, and plotted again as a function of Wavelength vs distance from the wire, lining up the bins of each element next to one another.



Conclusions

- Wavelength varies inversely with atomic number, ranging from 324µm for W to 467µm for Ni.
- Wavelength increases as a function of distance from the wire.
- After peak current, trends are less apparent.
- Nickel consistently behaves differently than the other materials examined here.
- Wavelength for all materials increases with distance from the cross-point, as B_{global}/B_{local} decreases.

References

[1] IDEA, V1.7, Graz University of Technology, Austria (http://optics.tu-graz.ac.at)
[2] A.J. Harvey-Thompson *et al*, *Phys. Plasmas*, **16**, 022701 (2009)
[3] J.P. Chittenden *et al*, *Phys. Rev. Lett.*, **101**, 055005 (2008)
[4] F. N. Beg *et al*, *IEEE Trans. Plasma Sci.*, **30**, 552 (2002)

http://cer.ucsd.edu/hedp