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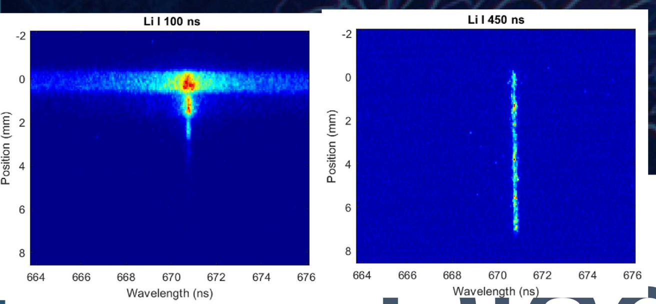

Diagnosing Electrode Surfaces on the Z-Machine Using Optical Spectroscopy

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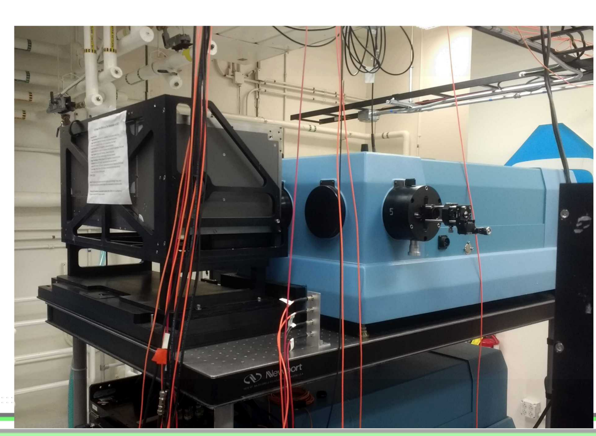
Abstract

Currently, optical spectroscopy is used on the Z-machine to characterize electrode surface conditions and plasma formation during the Z power pulse. Such measurements are needed to inform theory and simulation efforts to design next-generation pulsed power machines. Several diagnostic techniques and resulting measurements will be discussed, including surface electron densities using Stark broadened line emission from passive dopants, radiance estimates from absolutely calibrated streak spectra, and low temperature (under 5000 K) measurements of cathode surfaces using high gain calibrated avalanche photodiodes. Additional capabilities using laser activated dopants that are presently being developed to probe regions with lower electron densities (less than 10^{17} cm^{-3}) will also be described.

Experimental Overview

Z can deliver a 27 MA pulse within a 100 ns risetime. However, on several loads loss currents exceed 1 MA.[1] Measurements of the electrode surface temperatures provide a direct comparison to models to help benchmark and create more predictive codes.



An absolutely calibrated streak spectrometer is lens coupled to a fiber optic cable which is used to image a 1-2 mm region on electrode surfaces on Z. Parameters of the streak spectrometers are:

- 1m McPherson spectrometer
- 50 g/mm grating
- ~1.7 nm spectral resolution
- 200 ns-500 ns sweep window

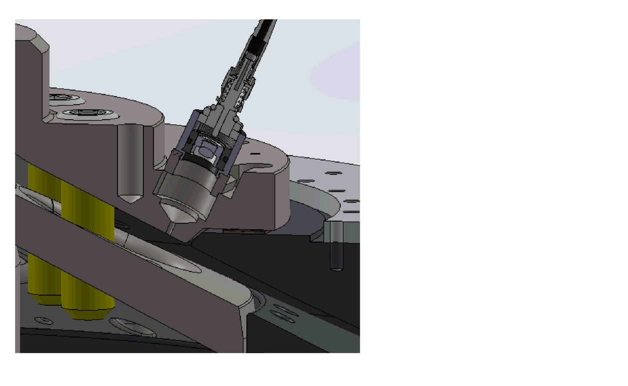
Streaked spectra are corrected for (in addition to wavelength and time):

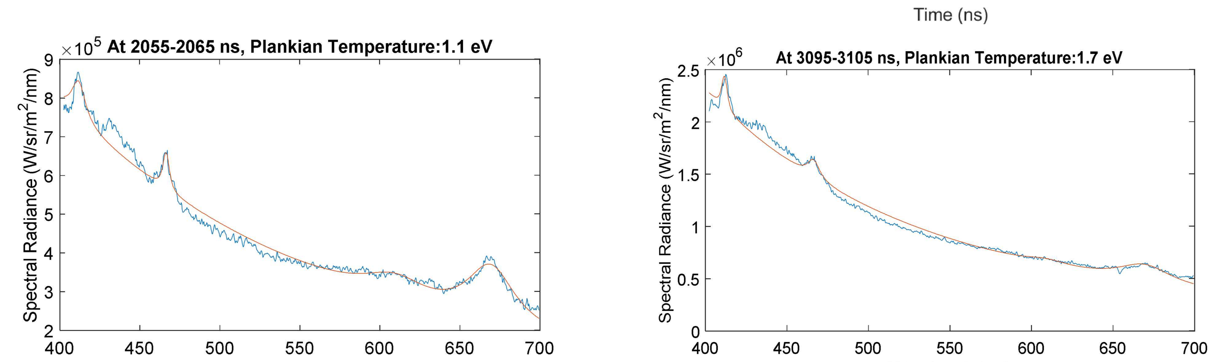
- Geometric Distortions
- Wavelength dependent fiber transit time (dispersion)[2]
- Spectral radiance

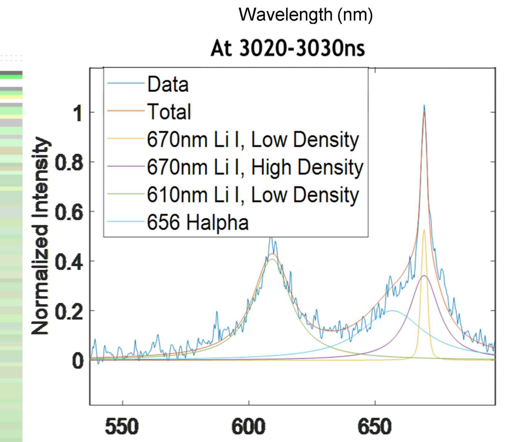
Absolute Calibration

- The systems have a "slow sweep" capability which allows for sweep windows of several seconds.
  - A tungsten lamp of known spectral radiance is coupled to an integrating sphere and imaged over a sweep window of 8s.
  - A laser driven light source (LDLS) is imaged on the slow and 200-500ns sweep speeds to correct non linearities between sweep rates.
  - In order to estimate errors a fiber of known geometrical extent (Numerical aperture: 0.22, Diameter: 100 um) images a several watt laser through a diffuser. Estimated error is about 15%.

Surface Measurements

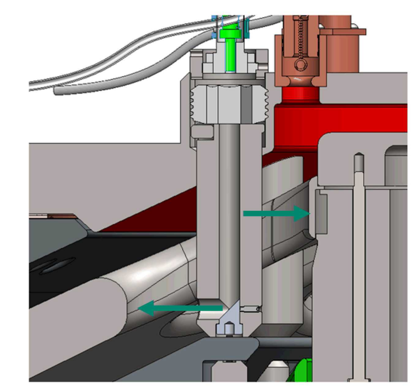




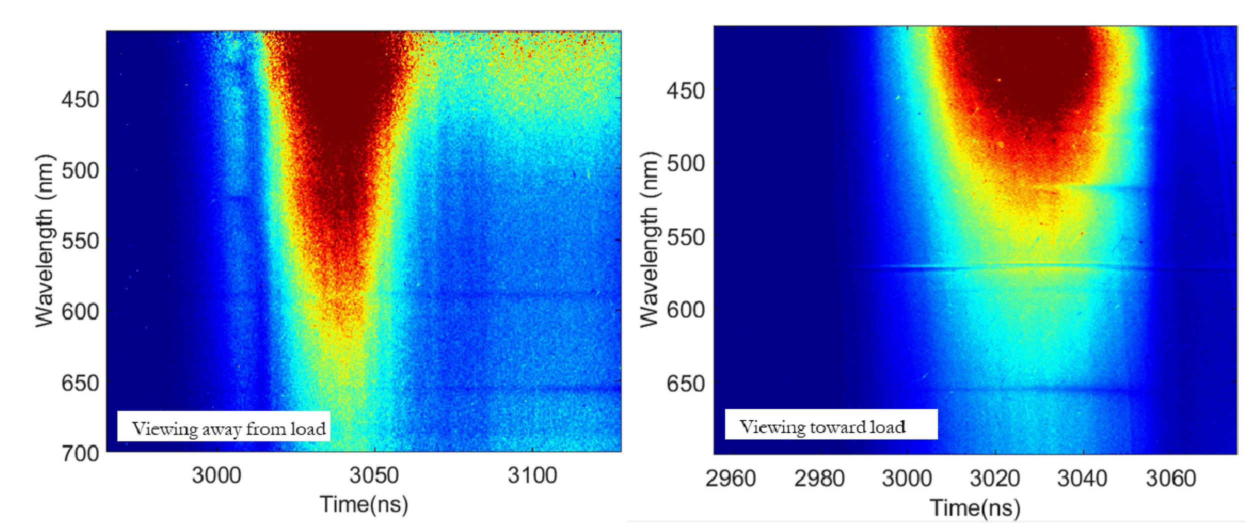


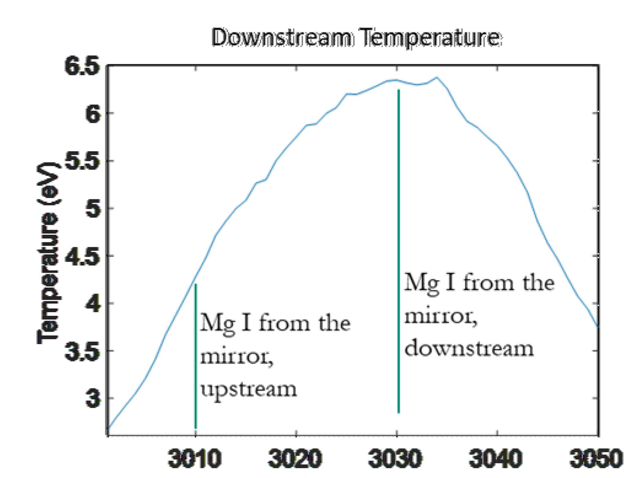
- Viewed upstream of the load
- Relatively benign region with zero to little plasma formation on the anode.
- Potentially a good region to benchmark power flow codes.

- LiF dopant was used to estimate electron density from the Li I transitions.
- Lines are fit with a high and low density component to account for the highly broadened wings in the line profiles
- Stark widths[3] and shifts suggest densities that range from 5^{18}/cc from Ha to 4-6^{17}/cc from Li I. The range in density may be attributed to density gradients along the light of sight, with a high density, cooler surface.

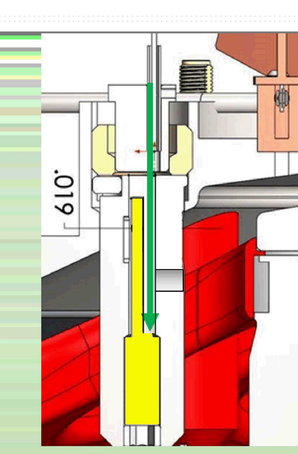


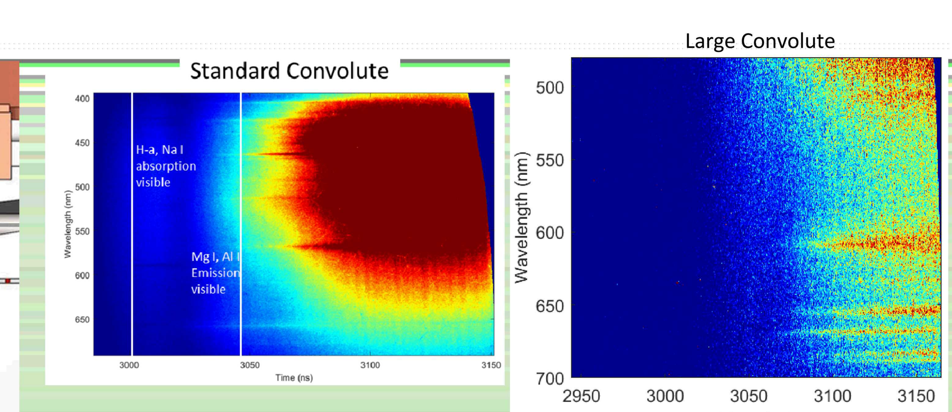
- Viewed upstream and downstream of the load.
- Measured asymmetries in the post hole convolute
- Measured the effect of a magnetic null on plasma formation

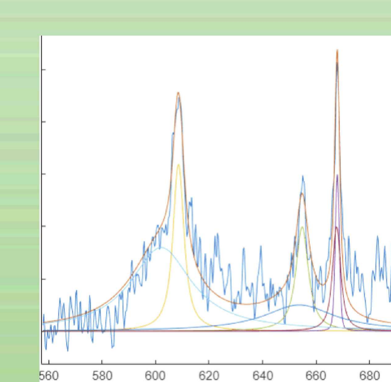




- Magnetic null likely causes anode plasma formation on the post when viewing upstream of the load
- Estimated electron densities by 3010ns upstream are mid 10^{17}/cc-10^{18}/cc, which occurs at 3035 ns on the downstream post.



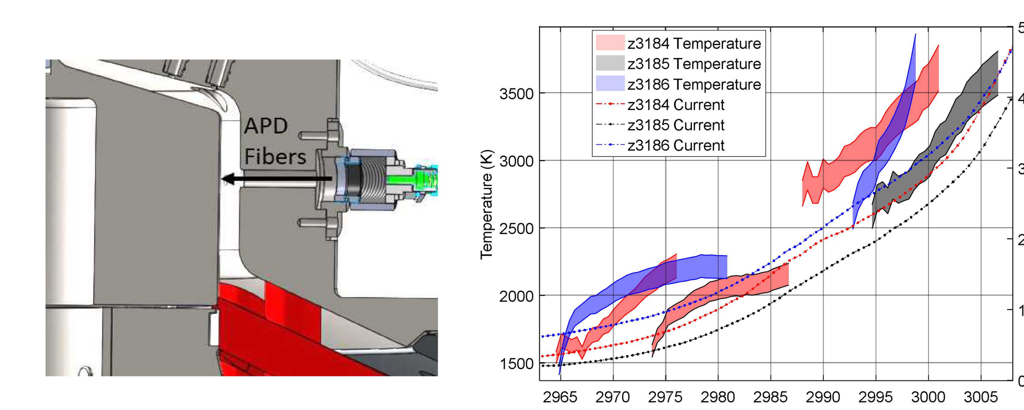




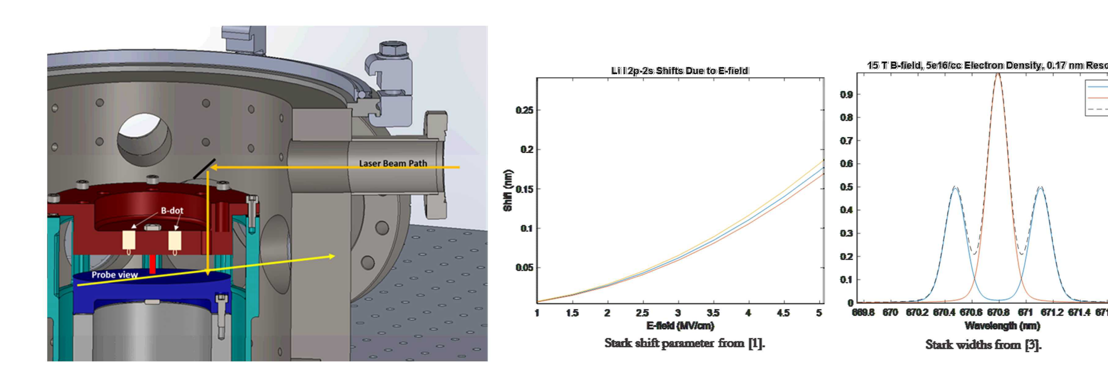
- Anode conditions can more easily be deconvolved by viewing parallel to the anode.
- Here a comparison between two different convolutes are shown.
- The larger convolute prevents plasma formation on the anode.
- A line out at 3088 ns shows the large convolute anode plasma is at an electron density of 3^{17}-3^{18}/cc, which occurs by 3040 ns on the standard convolute

Avalanche Photodiodes

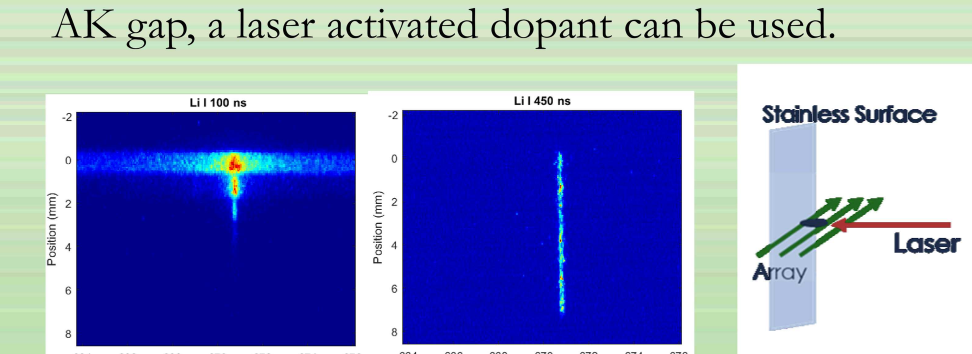
- Filtered and calibrated avalanche photodiodes (APDs) can be used to estimate early time temperatures, prior to when streak spectroscopy can be used.
- Temperature, assuming a black/graybody surface, can be calculated using the APD spectral response, wavelength dependent transmission, and the probe's geometric extent, from the APD voltage.
- Solid stainless emissivity is used as the lower bound, and an emissivity of 1 is used as the upper bound.



Active Dopants



- Surface measurements result in strong signals, at high densities which result in continuum and/or Stark dominated measurements.
- To measure lower density regimes, such as further into the AK gap, a laser activated dopant can be used.



- Results in densities less than 10^{17}/cc
- Changes in the line shape during the power pulse on Z can be attributed to MITL conditions
- Low density line shapes can be used to reliably diagnose field strengths

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