Sandia National Laboratories

Measurements of Z Electrode Temperatures Using Absolutely Calibrated Streaked Visible Spectroscopy Systems and Avalanche Photodiodes

Sonal G. Patel, Mark D. Johnston, David E. Bliss, George R. Laity, Matthew R. Gomez, Ross E. Falcon, Daniel J. Scoglietti, Keven MacRunnels, Mark E. Savage, Michael E. Cuneo

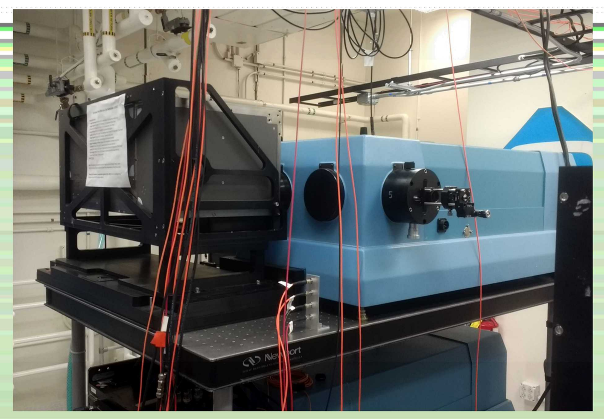
Abstract

Absolute calibration of streaked visible spectroscopy systems has been performed at Z-machine at Sandia National Labs in order to determine temperatures of electrode surfaces during the current pulse. The calibration procedure involves imaging a blackbody light source, with a known spectral radiance which is coupled to an integrating sphere. This source is streaked slowly over a few ns using spectrometer's coupled to Sydor streak cameras. The slow sweep is converted to a 100-500ns sweep by imaging a bright light source on both sweep rates, and obtaining wavelength and time dependent correction curves. Any broadband light source or several laser lines of differing wavelengths can be used for this correction. This technique has yielded temperature estimates of several eV in the Z convolute.

An additional technique using spectrally calibrated avalanche photodiodes with high gain is used to estimate MITL temperatures early in the current pulse, below the threshold that the streaked visible spectroscopy systems can measure. Temperatures of a few thousand kelvin are estimated before the measurement saturates.

Experimental Overview

Z can deliver a 27 MA pulse within a 100 ns risetime. However, on several loads loss currents exceed 1 MA.[1 Gomez.] 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
- ~3 nm spectral resolution
- 200 ns-500 ns sweep window

Calibration Procedure

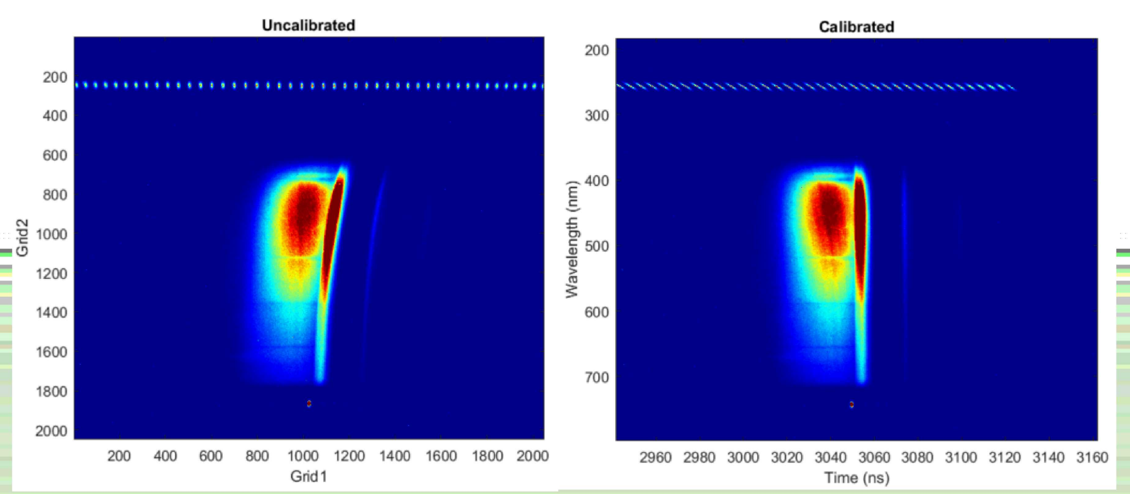
Streaked spectra are corrected for (in addition to wavelength and time):

- Distortion
  - Using the Sydor streak cameras internal reticle patterns
- Wavelength dependent fiber transit time (dispersion)[2]
  - $\tau = \frac{L}{c}\left(n - \lambda\frac{dn}{d\lambda}\right)$, where n is the refractive index and L is the length of the fiber.
- Spectral radiance

Spectral Radiance

- Temperatures are estimated from the continuum using absolutely calibrated systems.
- 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.
  - The conversion from an 8s window to 200-500ns is not perfectly linear and so a laser driven light source (LDLS) is imaged on both sweep rates, which corrects the 8s slow swept tungsten lamp spectra to a fast swept spectra.

Z3214



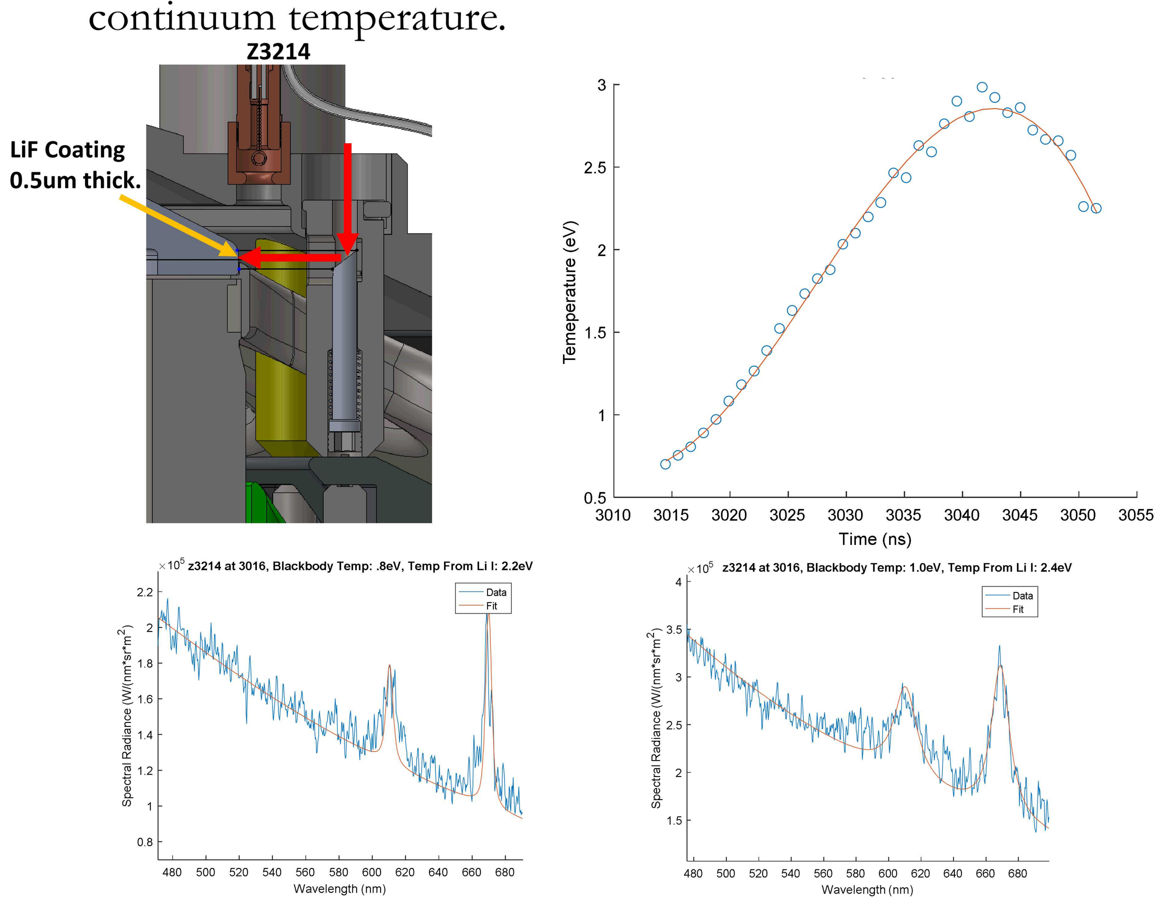
Errors

- 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.
- The calibration procedure is applied to this spectra, and a power is calculated using the geometrical extent of the fiber.
- Error of about 15%

Results

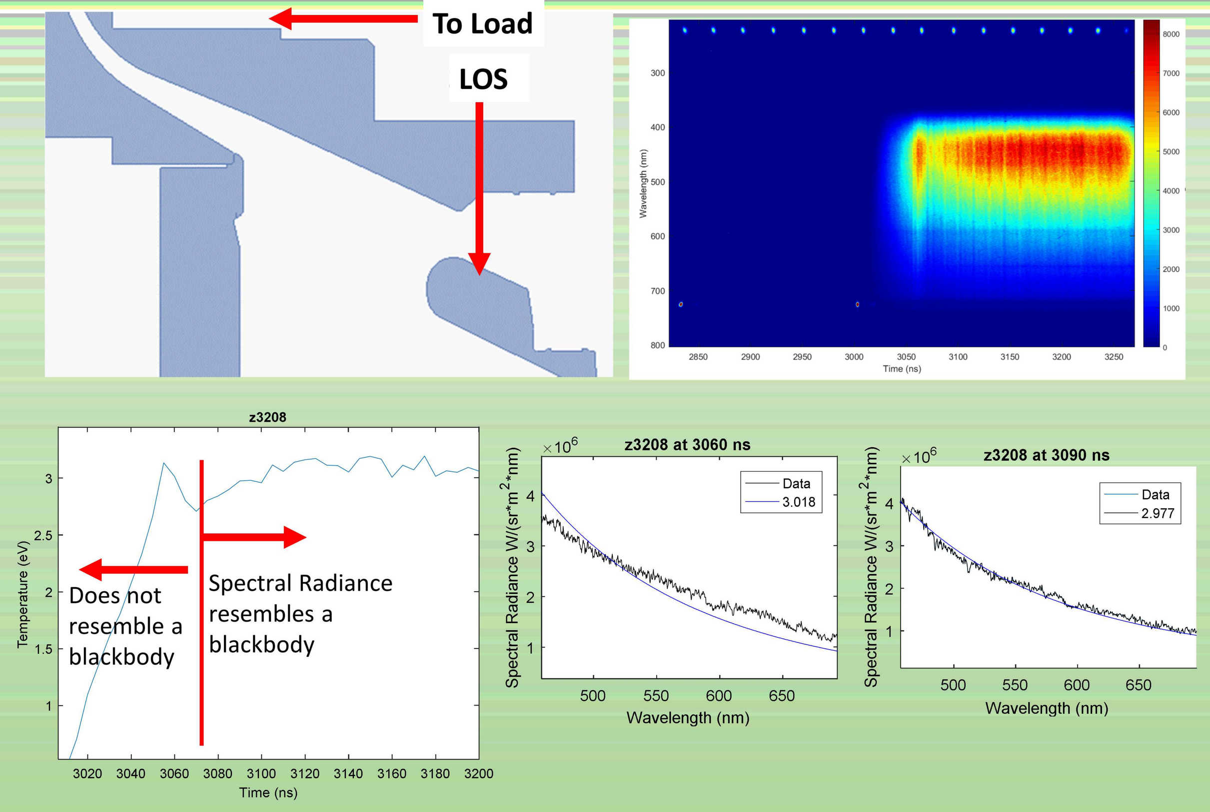
All results presented here are **assuming a blackbody with emissivity 1.**

- Lower emissivity would increase estimated temperature from the continuum. Optically thin spectra would reduce the estimated continuum temperature.



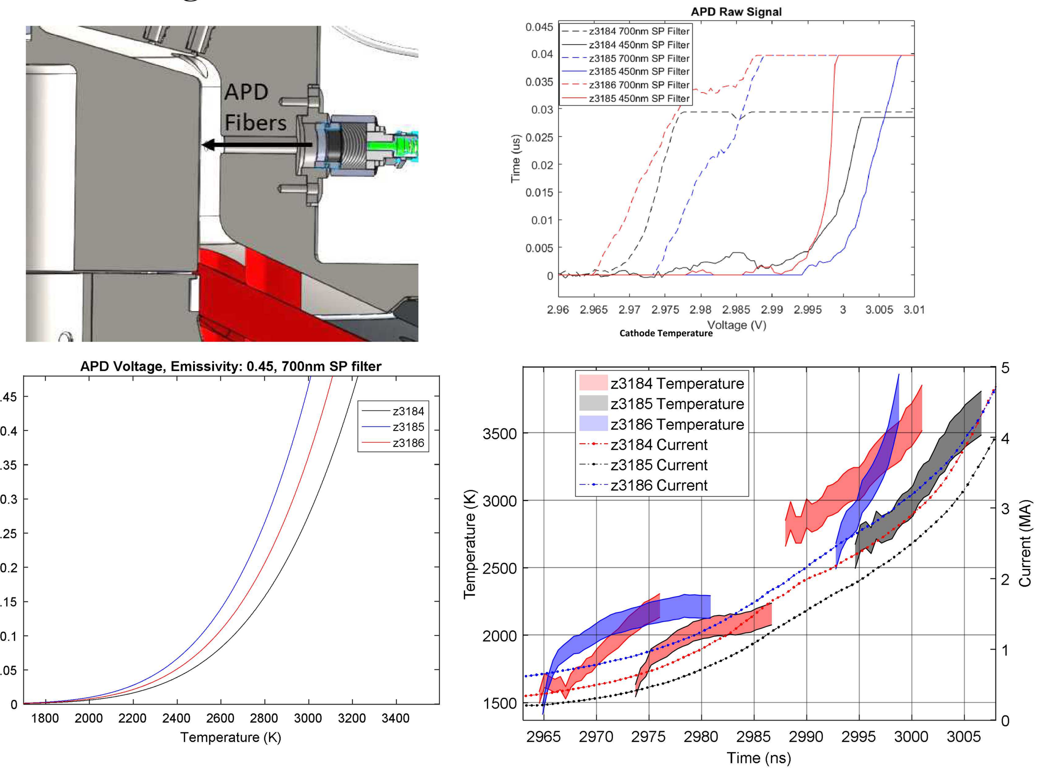
z3208

- Measurements taken just outside the convolute region.
- Peak temperatures occur much later than z3214
- Optically thick region likely must occur after 3075 ns.



Avalanche Photodiodes

- Filtered and calibrated avalanche photodiodes (APDs) were fielded coupled to a fiber optic probe.
- 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.



- Emissivity of stainless is not well characterized in the molten state, but is in the solid. Emissivity of metals:
  - increases with decreasing wavelength
  - increases with increasing temperature
  - Is higher at molten surfaces than at solid surfaces,
  - Hemispherical emissivity is higher than the normal.
  - Solid stainless steel emissivity of 0.451[2], at normal incidence and at IR wavelengths is used as a lower bound, which results in an upper bound on the temperature. An emissivity of 1 is used for an upper bound.

Future Work

- Evaluate errors associated with the blackbody assumption
- Improve efficiency of the streak and APD systems to measure lower temperatures
- Create an in-situ measurement of the calibration error for the streak spectrometer measurements.
- Continue and compare measurements at several radii on Z.

1. M. R. Gomez, et al. Experimental study of current loss and plasma formation in the Z machine post-hole convolute," *Phys. Rev. Accel. Beams,* 2017.
2. G. Cao, et al, "Spectral emissivity of candidate alloys for very high temperature reactors in high temperature air environment," *Journal of Nuclear Materials*, 2013.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology &Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. ____________

Sandia National Laboratories