Relative Quantum Efficiency Measurements of the ROSS Streak Camera Photocathode

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Abstract

Streak cameras are vital to the daily functioning of the LLE facility, providing the ability to time-resolve high-speed processes occurring in the fusion environment. Even with standardized cameras, such as the Rochester Optical Streak System (ROSS), readings on an identical source can vary over multi-year timescales. Many factors may contribute to these fluctuations, but the most likely cause is degradation of the photocathode. Measuring the absolute quantum efficiency of a streak tube's photocathode is a lengthy and expensive process. The goal of this project was to develop a simple method of determining a ROSS camera photocathode's relative quantum efficiency quickly in a lab setting. This would allow the photocathode response to be monitored on a yearly basis. Furthermore, a method of converting relative measurements into absolute measurements was investigated.

Background

The photocathode element inside the streak tube converts light intensity into an electron current density through the photoelectric effect. The streak tube then converts the electron signal into an image of light intensity vs. time. The photocathode itself is a thin (~100 nm) thick layer of photoemissive material. The two variants used in the ROSS cameras are S1 and S20 photocathodes. The S1 is a silver oxide compound, whereas the S20 is sodium/potassium/antimony; both are doped with cesium. Cesium is used because it has the lowest work function of all elements.

The signals these tubes produce will degrade over time even though the tubes are kept evacuated to increase the mean free path of the electrons to a few kilometers. The major source of degradation comes from ion feedback. A very small fraction of the electron beam generated by the photocathode will collide with the residual gas molecules in the tube, creating ions that are accelerated back to the photocathode, causing severe physical damage. This degradation occurs continuously due to the inherent dark current, thermally excited electrons emitted spontaneously from the photocathode. This dark current creates a noise level in all readings taken by the device and can easily drown out weak signals. Each photocathode type has a specific spectral response[1], (**Figure 1**). As the photocathode ages the quantum efficiency will decrease, predominantly at the longer wavelengths. Eventually the streak tube will be deemed non-responsive. The current solution to this problem is to replace the camera and to diagnose the detailed status of the tube through a lengthy and costly absolute quantum efficiency measurement. The goal of this project was to create an alternative method of diagnosing and evaluating this degradation.

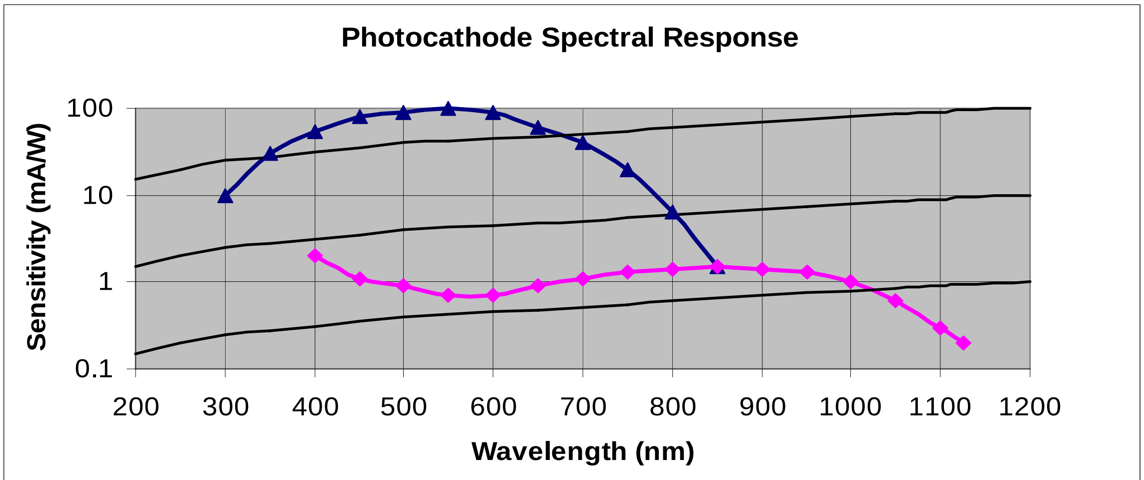

Figure 1: Spectral response of two common photocathodes. The S-20 variant is the upper line and S-1 is the lower line. The black curves are .1%, 1%, and 10% quantum efficiency lines from the bottom respectively. (2)

Experiment

The system to be designed, to provide relative quantum efficiency, had a few prerequisites. It was to be compatible with ROSS cameras and provide a stable illumination source. The source's intensity and wavelength had to be easily controlled by the user, and the device had to connect to the ROSS camera in a light-tight fashion. LEDs were chosen as the illumination source because they are cheap, stable, reliable and controllable. Also specific wavelengths can be easily selected for testing. An opal glass diffuser was placed in front of the LED to spatially homogenize the light output.

The method in which the relative measurements would be taken is dependent on the structure of the streak tube itself. The tube is normally operated with the photocathode at -15 kV and various other voltages on the other internal electrodes. The photocathode response can, however, be accurately measured at much lower voltage. A potential of -50V was applied to the photocathode to facilitate electron emission. All of the other internal electrodes were connected together to the common ground. This grounding allows us to measure the total output current as accurately and non-invasively as possible. We measured the current to the photocathode with an ammeter in series. The output current was run thorough a 1 MΩ resistor in parallel with a voltmeter; essentially an ammeter. Both meters allowed for current readings with nanoampere precision. The LED intensity was adjusted with a simple voltage regulator circuit controllable at the millivolt level, (**Figure 2**).

The external shell was printed on a 3D-plastic printer and painted black to block all external light, (**Figure 3**). This setup gave us relative quantum efficiency measurements of the photocathode, but these relative measurements could be easily converted into absolute measurements. This was accomplished by measuring the light intensity output with a CCD camera at the exact distance from the LED as the photocathode. The typical quantum efficiency of a silicon CCD detector (which is stable over time) was used to estimate the absolute LED intensity. Knowing the LED intensity at certain voltage levels, we can convert the photocathode current readings to an absolute quantum efficiency.

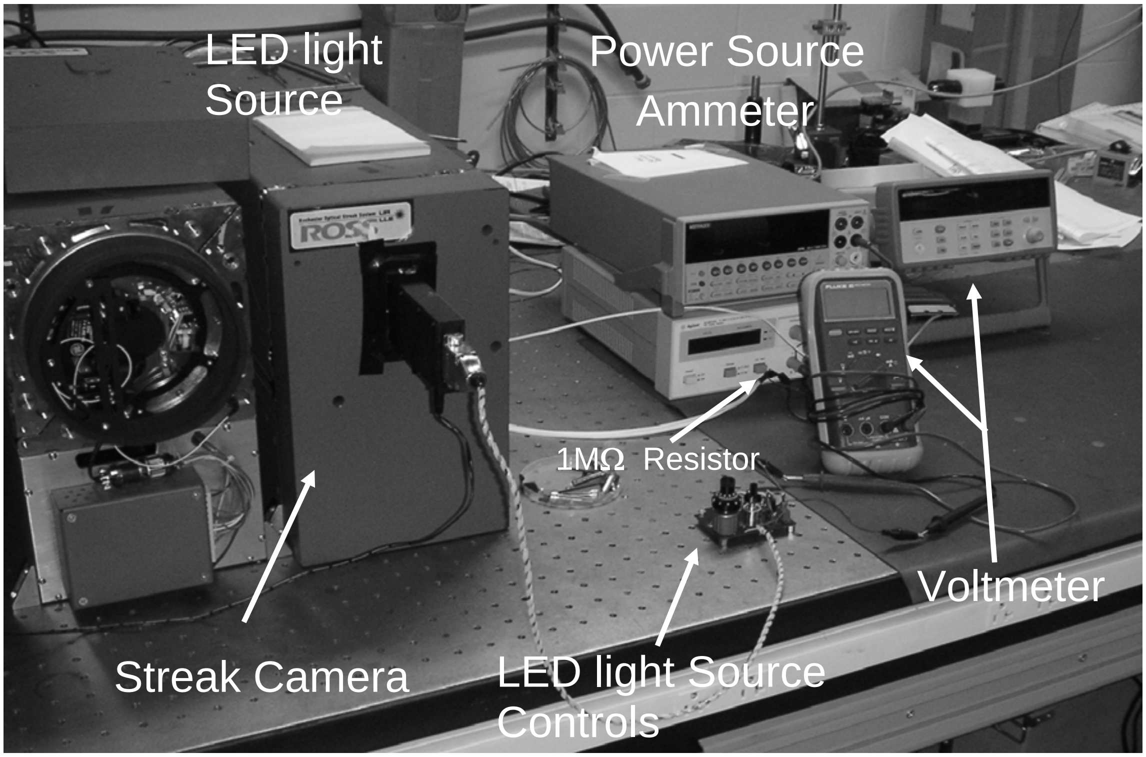

Figure 2: Experimental setup includes measurements of the input and output currents.

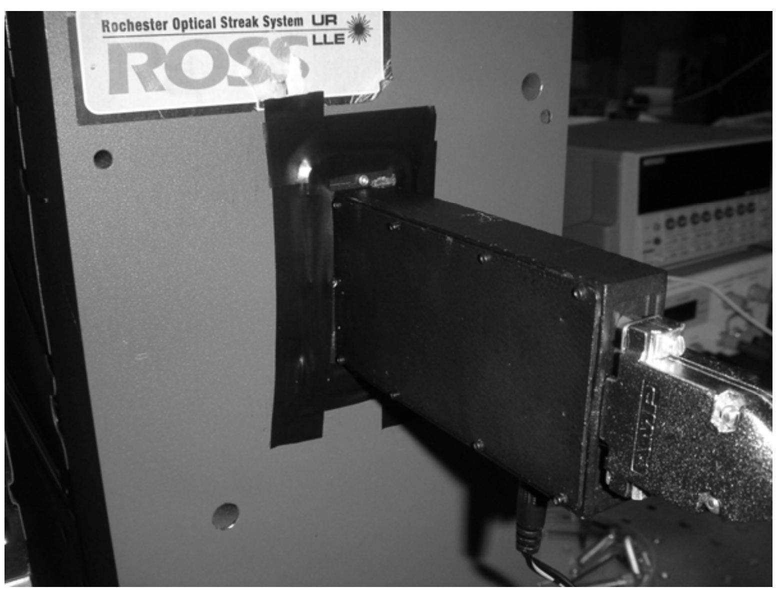

Figure 3: External LED housing with control and power cables, attached to a streak camera

Results

The photocurrent readings with the red/green/blue LED ranged from 0.1 to 100 nA. The angle of the LED with respect to the opal glass diffuser caused slight variations in the current readings. After modifying the LED mount, we were able to stabilize the readings and produce better data. Multiple readings of the same streak tube taken over a two week period were reproducible and show that the relative quantum efficiency measurements can be used to monitor photocathode sensitivity. Also, using the CCD camera to monitor the input light level, the relative measurements can be converted into absolute. The absolute measurements show some discrepancy with the manufacture's data sheet[2], (**Figure 4**). This can be due to an error in the estimated CCD quantum efficiency, and also a variation in the spatial uniformity of the photocathode sensitivity.

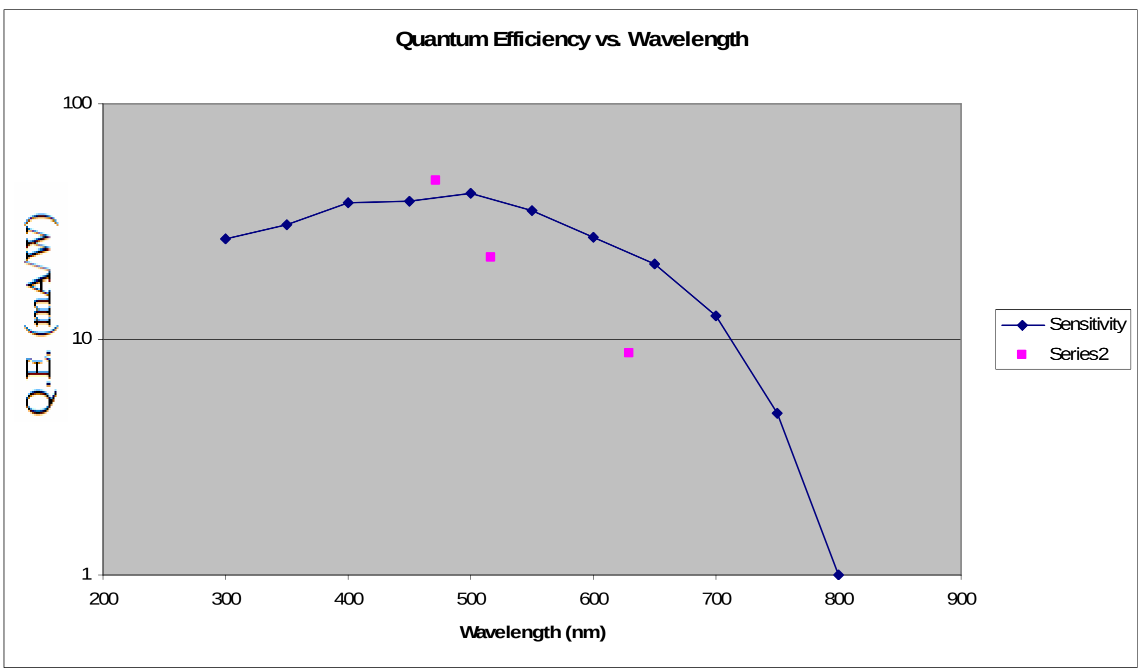

Figure 4: Referenced relative measurements: The readings that were taken at the three different wavelengths were referenced with intensity calculations derived from CCD camera readings. These crude absolute measurements were then overlaid on an average spectral response of a S-20 photocathode to estimate the accuracy of our relative to absolute conversion method.

Conclusion

The main purpose of this project was to demonstrate the effectiveness of using relative quantum efficiency measurements to diagnose streak camera photocathode degradation. The device was easily able to generate substantial readings well above the dark current noise floor with minimal illumination. Converting these relative measurements into absolute was also investigated and found to be equally promising. The five ROSS cameras that were evaluated for this project now have a baseline from which future quantum efficiency measurements can be referenced.

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