Performance of Multi Alkali Cathode in JLab DC Gun

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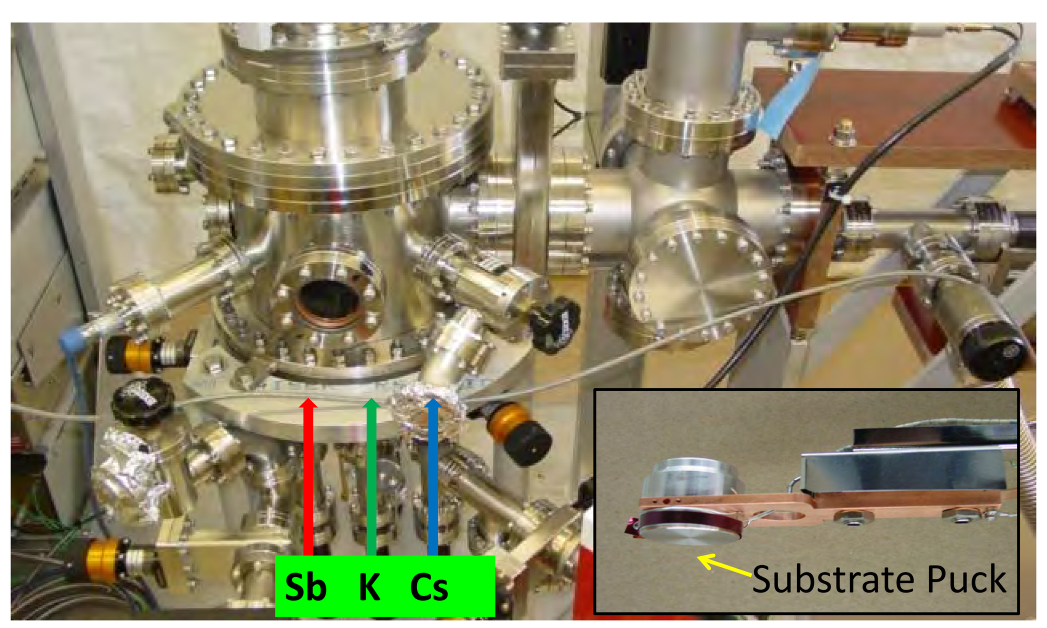
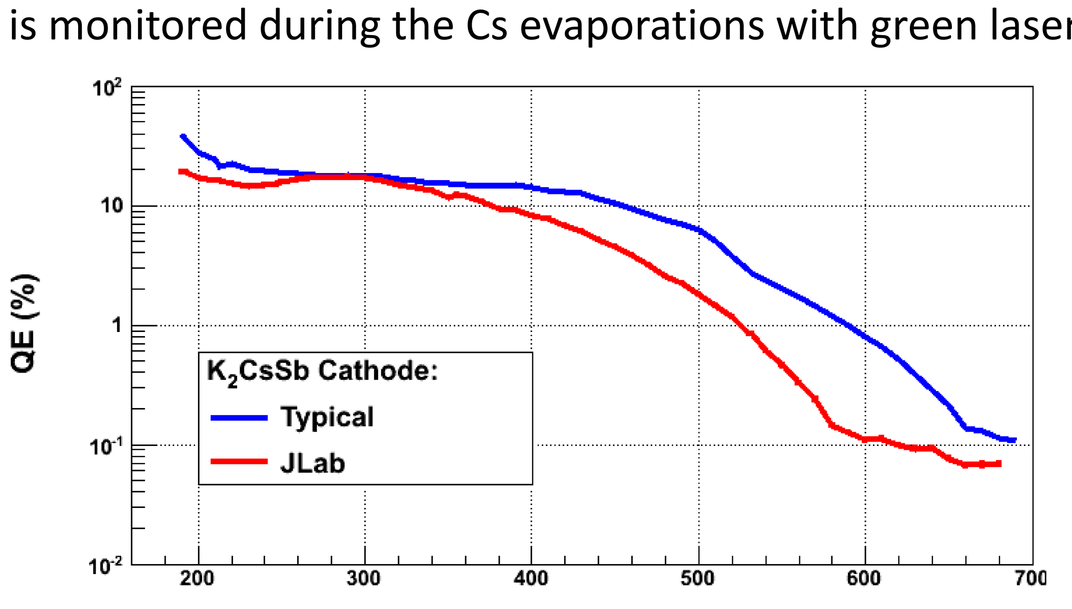
Abstract

In the past decade, there has been considerable interest in the generation of tens of mA average electron current photoinjector for use in current and future accelerator applications. Some applications include Free Electron Lasers and the proposed Electron Ion Collider. Two photocathodes are frequently considered for generating high average current electron beams and/or beams with high brightness: GaAs:Cs and CsK_2Sb. Each photocathode has advantages and disadvantages, although some attributes are based on assumptions and not demonstrated performance at "production" accelerator facilities. Until recently, the GaAs:Cs photocathode has been tested extensively in a DC field and CsK_2Sb in an RF field. To make a well-informed choice for new accelerators, the performance of both photocathodes should be measured under identical conditions. To this end the Polarized Source Group at JLab has partnered with the Laser group in the Instrumentation Division at Brookhaven National Lab (BNL) to evaluate CsK_2Sb in the same DC field that has been used to study GaAs:Cs. In March of 2011, a CsK_2Sb photocathode was grown at BNL and successfully transported in vacuum to the Injector Test Stand electron gun at JLab. Since then the quantum efficiency has been monitored, e.g. photocathode lifetime, under average currents ranging from 1mA-20mA, with different laser wavelengths.

BNL Deposition Process



- Custom Al puck with Stainless Steel disc bonded to top surface.
- Substrate Puck heated to 130°C
- Sb, K, and Cs evaporated in successive layers and allowed to diffuse to form CsK_2Sb
- Several hundred nm built up
- QE is monitored during the Cs evaporations with green laser



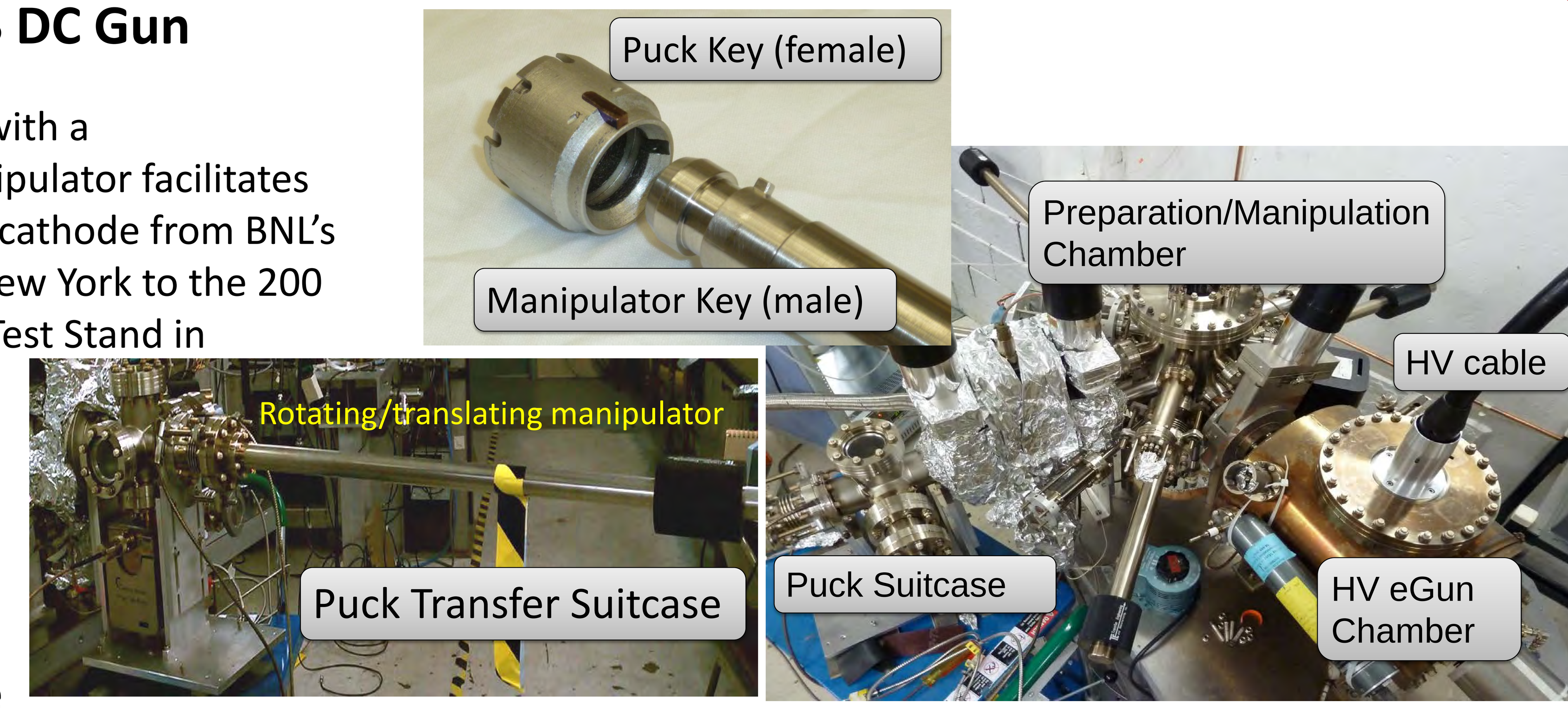
During the Jlab cathode preparation, the K dispenser ran out, resulting in a top surface that has higher Cs concentration than stoichiometrically stable CsK_2Sb.

Transport to JLAB DC Gun

A high vacuum suitcase with a rotating/translating manipulator facilitates the transfer of the photocathode from BNL's deposition chamber in New York to the 200 kV gun at Jlab's Injector Test Stand in Virginia.

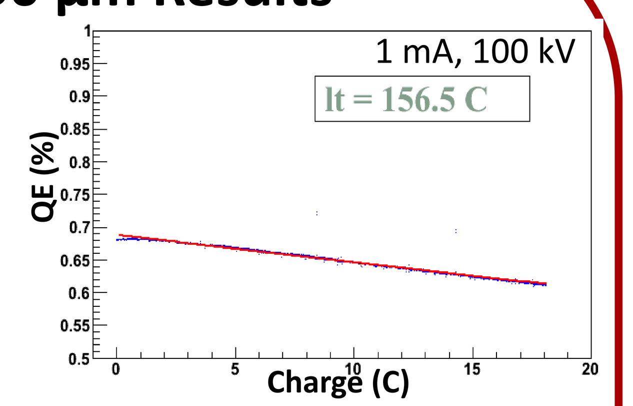
During this transfer or when the cathode is not in use there is no detectable loss of QE

Long Dark Lifetime

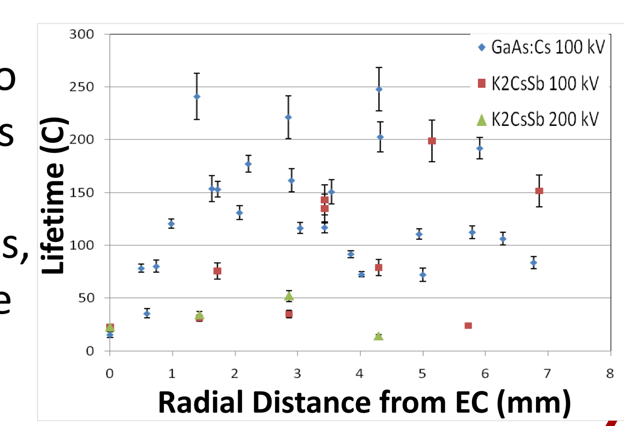


Initial 532 nm, 350 µm Results

Initial results for the quantum efficiency (QE) evolution with 532 nm, 350 µm spot size, shown as a function of accumulated charge fit with an exponential decay function (top).



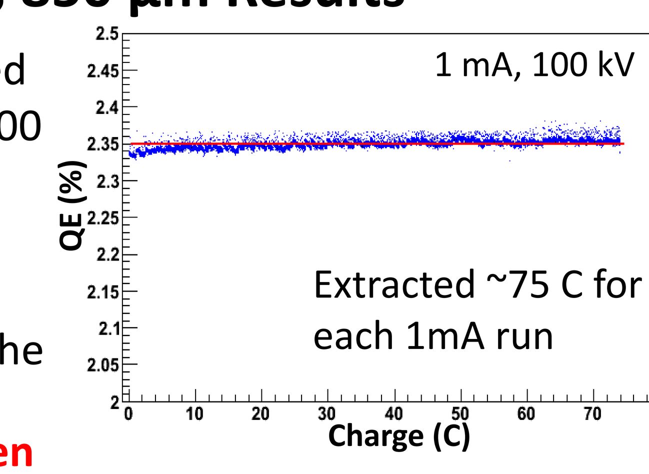
The results are similar to those seen with GaAs:Cs despite different bias voltages and beam spots, shown as radial distance from the electrostatic center (EC), on the photocathode.



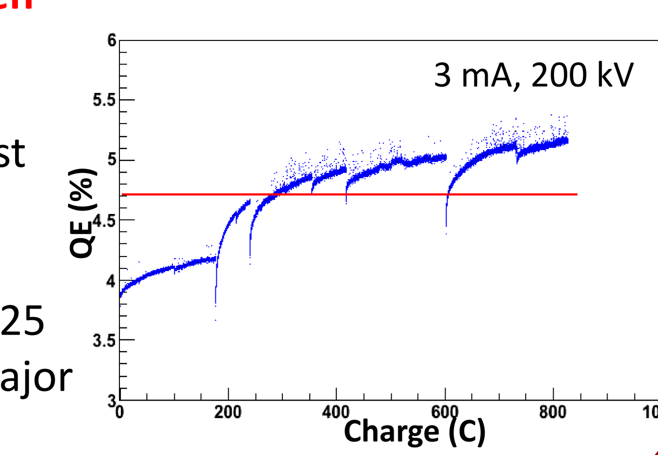
Initial 440 nm, 850 µm Results

No QE decay observed for all 1 mA runs at 100 and 200 kV bias voltages and every spot tested on the cathode, even from the EC!!!

Would never happen with GaAs:Cs!



Cathode is very robust to short pressure increases in the beamline and gun. 825 C extracted before major vacuum event.



Life After Major Vacuum Event

Short vacuum events cause the QE to drop briefly, but then recovers and sometimes improves as a result → **Robust Photocathode**

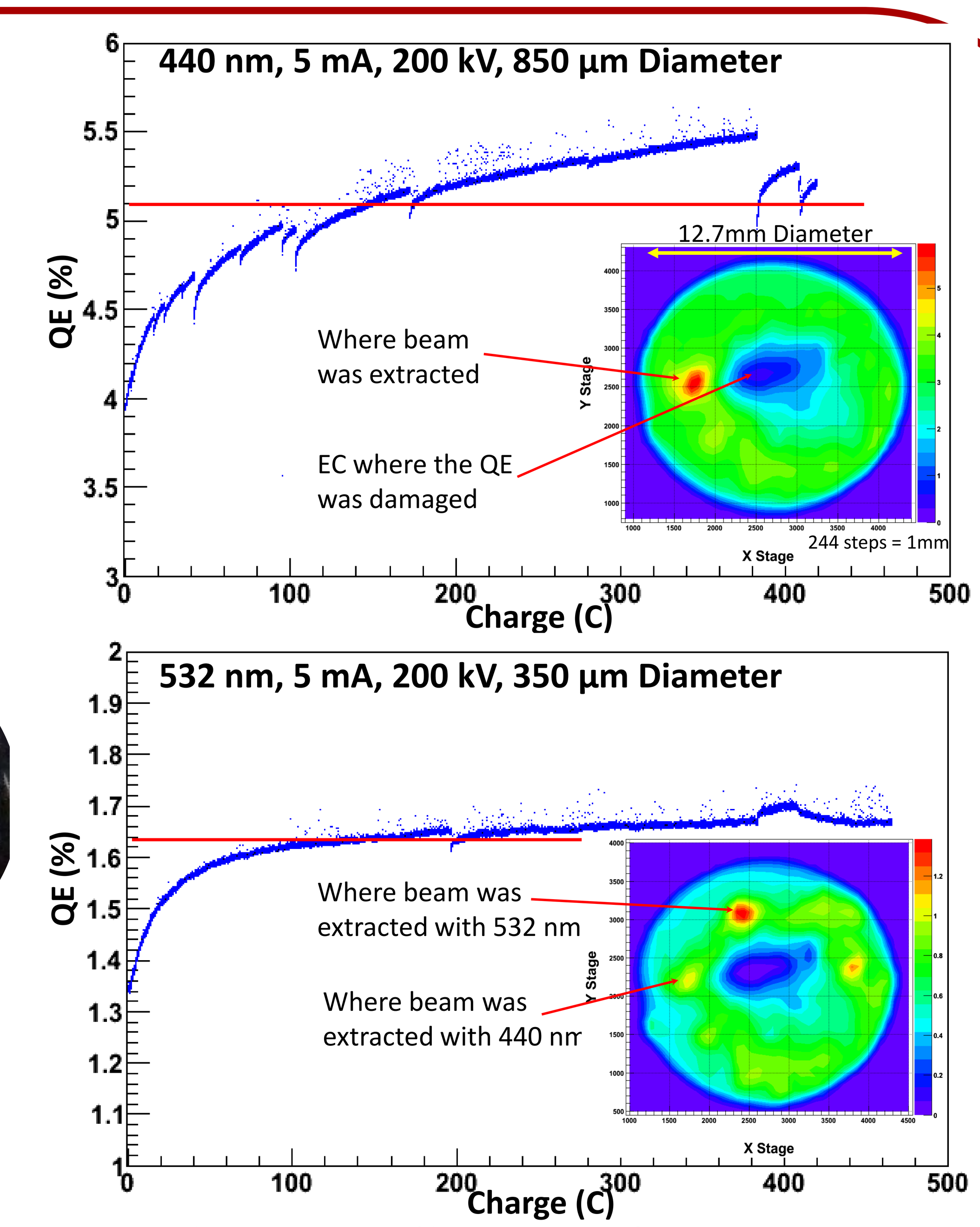
However, a power glitch caused some beam steering magnets to turn off causing the electron beam to scrape a portion of the beam pipe. The high voltage and laser were not affected which resulted in beam being extracted from the cathode in $5x10^{-10}$ T environment for ~2hours (Major Vacu

Remarkably the cathode survived t major vacuum event, except for t which upon visual inspection looks to be sputtered away.

But, now the lifetime behavior at 532 nm shows no QE decay as well, least up to current ~ 10mA!!!

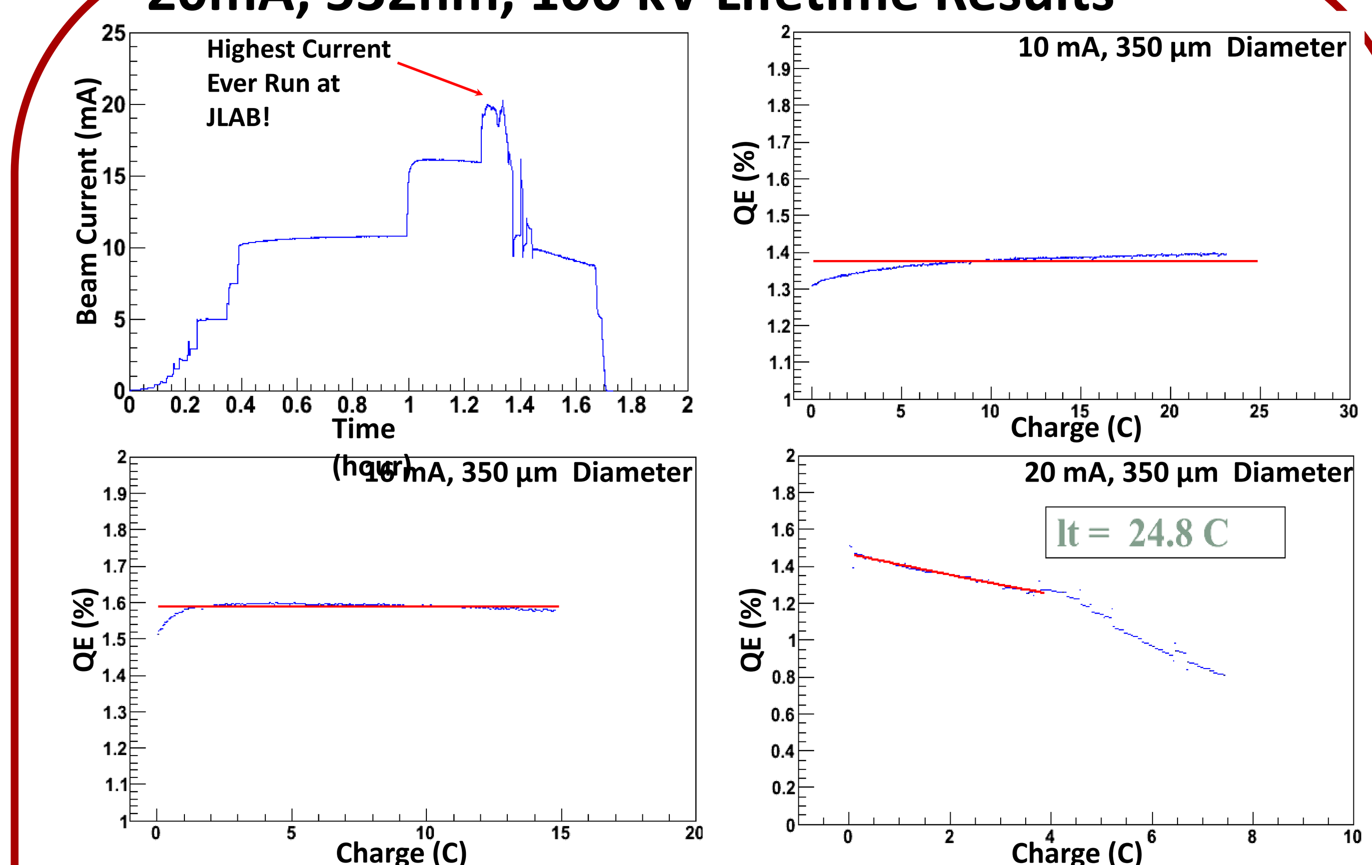
Also, the QE increase from running with 440 nm light shows up as an QE increase when using 532nm

Major vacuum event chemically changed the surface?



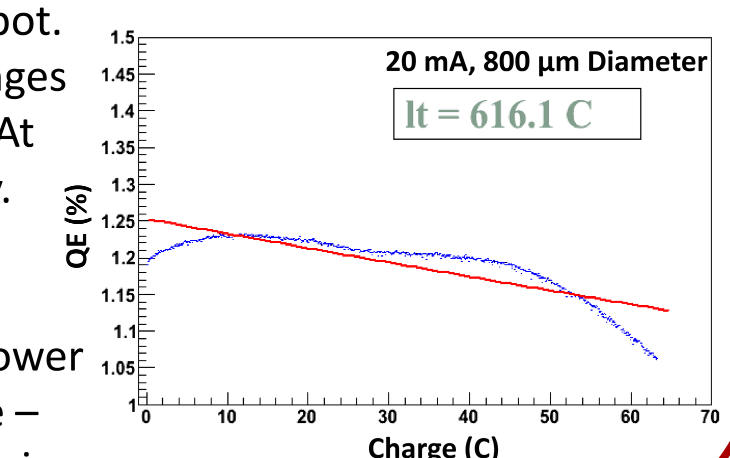
QE evolution at 5mA of beam current for 440 and 532 nm wavelengths. Inset shows a QE map of the photocathode after the ~24 run for each wavelength.

20mA, 532nm, 100 kV Lifetime Results



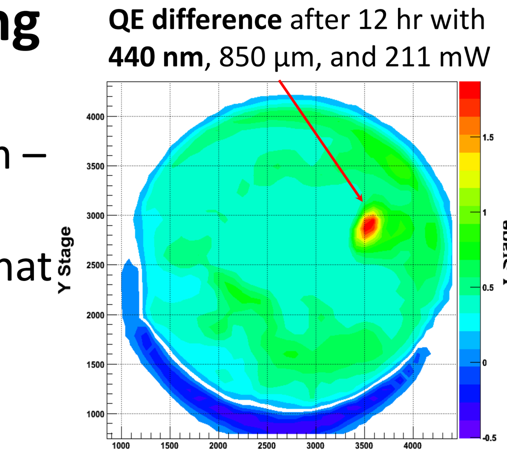
Ramped up to 20 mA beam current with a 350 µm diameter laser spot. Between 10-16 mA the QE changes from increasing to decreasing. At 20 mA, the QE falls dramatically.

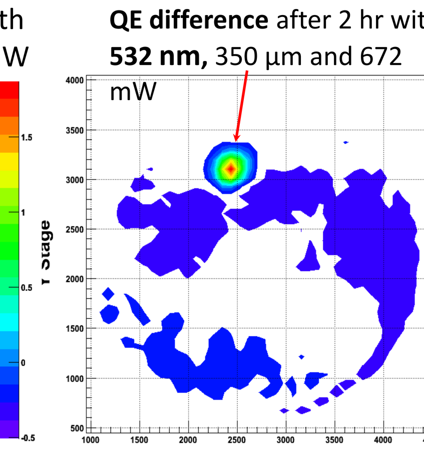
Increasing the laser spot size to 800 µm to decrease the laser power density did improve the lifetime – indicating laser heating is playing a role in the QE evolution.



Laser Heating

The QE increases without making beam – just illumination with light. We postulate that the stoichiometry of the photo-cathode is improving locally.





However there is a critical power density/temperature where beyond this the QE begins to decay at the illuminated spot.

Summary and Future plans

As prepared CsK_2Sb cathode showed no QE decay for up to 5 mA of beam current when using 440 nm light but exhibited ~100 C photocathode lifetimes for 532 nm.

→ Suggests absorption depth/surface dependent behavior.

After the major vacuum event the QE behavior at 532 nm began to mimic that at 440 nm light. Beam currents up to 20 mA where extracted with 532 nm light; the highest current ever extracted at Jefferson Lab. At these currents, laser heating emerges as a cause for QE decay.

→ Chemistry of the photocathode is critical to its QE behavior.

In total over 5000 C of charge have been extracted from this cathode.

Future Measurements

- Emittance measurements
- Lifetime in controlled vacuum around 10^{-9} Torr
- SEM/EDS measurements to quantify composition and morphology

Repeat Measurements on a more typical BNL CsK_2Sb cathode